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Space Shuttle Program

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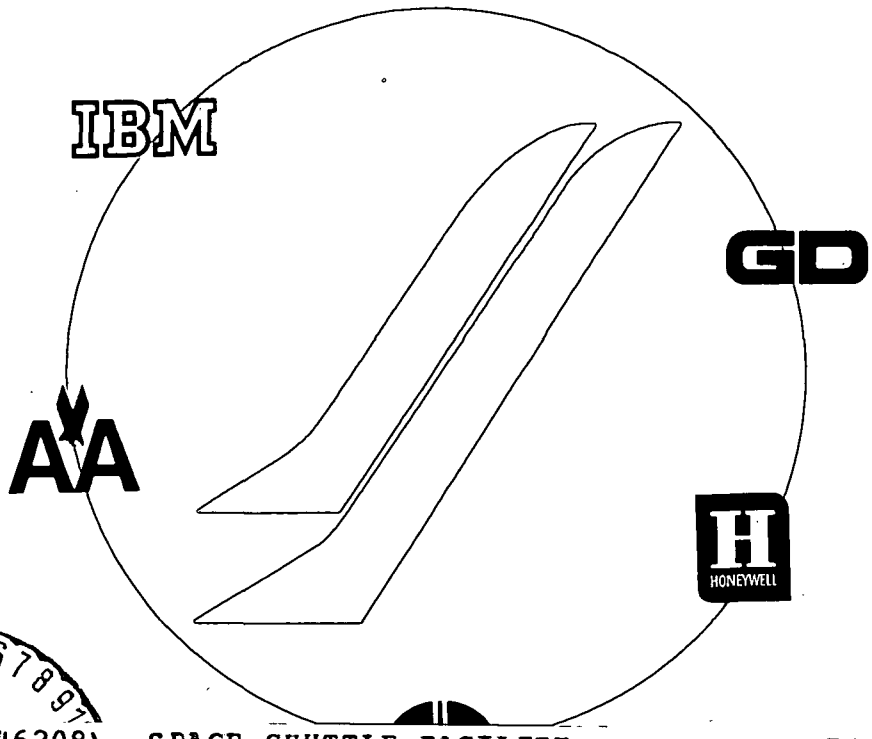

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Facility Utilization and Manufacturing Plan for Phase C/D

Volume I. Orbiter

Contract NAS9-10960
DRL M010, DRL Line Item 16
DRD TM001M
SD 71-104-1
25 June 1971

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SD 71-104-1
(MSC-03311)

25 June 1971

SPACE SHUTTLE

FACILITY UTILIZATION AND MANUFACTURING PLAN for Phase C/D

Volume I
Orbiter

Approved by

B. Hello
Vice President and General Manager
Space Shuttle Program

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DRL M010, DRL Item 16
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FOREWORD

This plan is one of a family of program plans that establish, as applicable, requirements and prospective implementation approaches for the conduct of Phase C (Design) and Phase D (Development and Operations) of the Space Shuttle Program. With the exception of the cost data, which appear in the Cost and Schedule Estimates Plan only, each plan has been prepared in accordance with the specific contract requirements described in the Contract NAS9-10960 Statement of Work, Paragraph 4.7 and Appendix A, Data Requirements. These plans are as follows:

Title	Volume	SD No.	MSC No.
Program Management Plan for Phase C/D	One volume	SD 71-101	MSC-03308
Engineering and Development Plan for Phase C/D	I. Shuttle System II. Orbiter System III. Booster System	SD 71-102-1 SD 71-102-2 SD 71-102-3	MSC-03309
Operations Plan for Phase C/D	I. Shuttle System II. Orbiter III. Booster	SD 71-103-1 SD 71-103-2 SD 71-103-3	MSC-03310
Facility Utilization and Manufacturing Plan for Phase C/D	I. Orbiter II. Booster	SD 71-104-1 SD 71-104-2	MSC-03311
Preliminary Test Plan for Phase C/D	I. Shuttle System II. Orbiter III. Booster IV. Shuttle Support Equipment V. Shuttle Software	SD 71-105-1 SD 71-105-2 SD 71-105-3 SD 71-105-4 SD 71-105-5	MSC-03312
Logistics and Maintenance Plan for Phase C/D	One volume	SD 71-106	MSC-03313
Program Cost and Schedule Estimates Plan for Phase C/D	One volume	SD 71-107	MSC-03314

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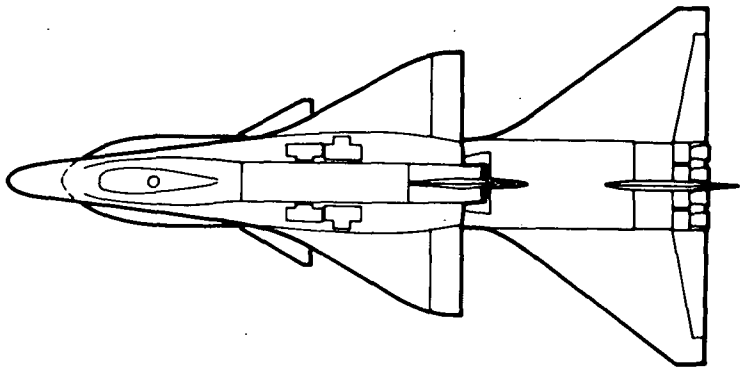
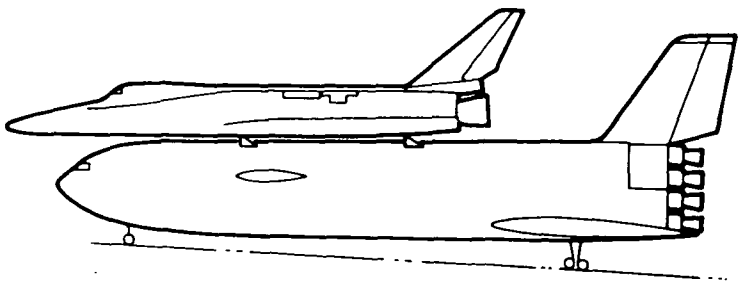
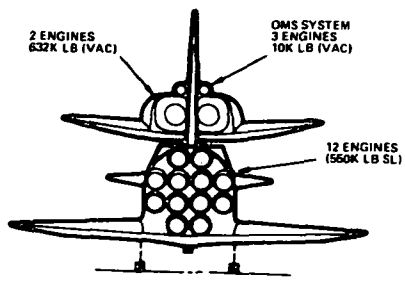
PREFACE

The objective of the Space Shuttle Program is to provide a low-cost space transportation system for placing and retrieving payloads in earth orbit. The first manned orbital flight is scheduled for April 1978. To achieve this goal, a reusable space shuttle system capable of a rapid turn-around, airline-type ground operation has been defined, satisfying as a minimum three basic missions: (1) 100-nautical-mile due-east circular orbit originating from a latitude of 28.5 degrees north, (2) a 55-degree inclination, 270-nautical mile earth orbit, and (3) a 100-nautical mile south polar circular orbit.

To accomplish these missions, a two-stage launch vehicle (shown below) has been defined, which is capable of delivering into orbit one stage with its payload. Each stage is capable of atmospheric entry and return to a designated landing site. The vehicle features moderate acceleration levels, a shirtsleeve cabin environment and quick turnaround capability. Operational facilities and system support equipment complement the flight vehicle.

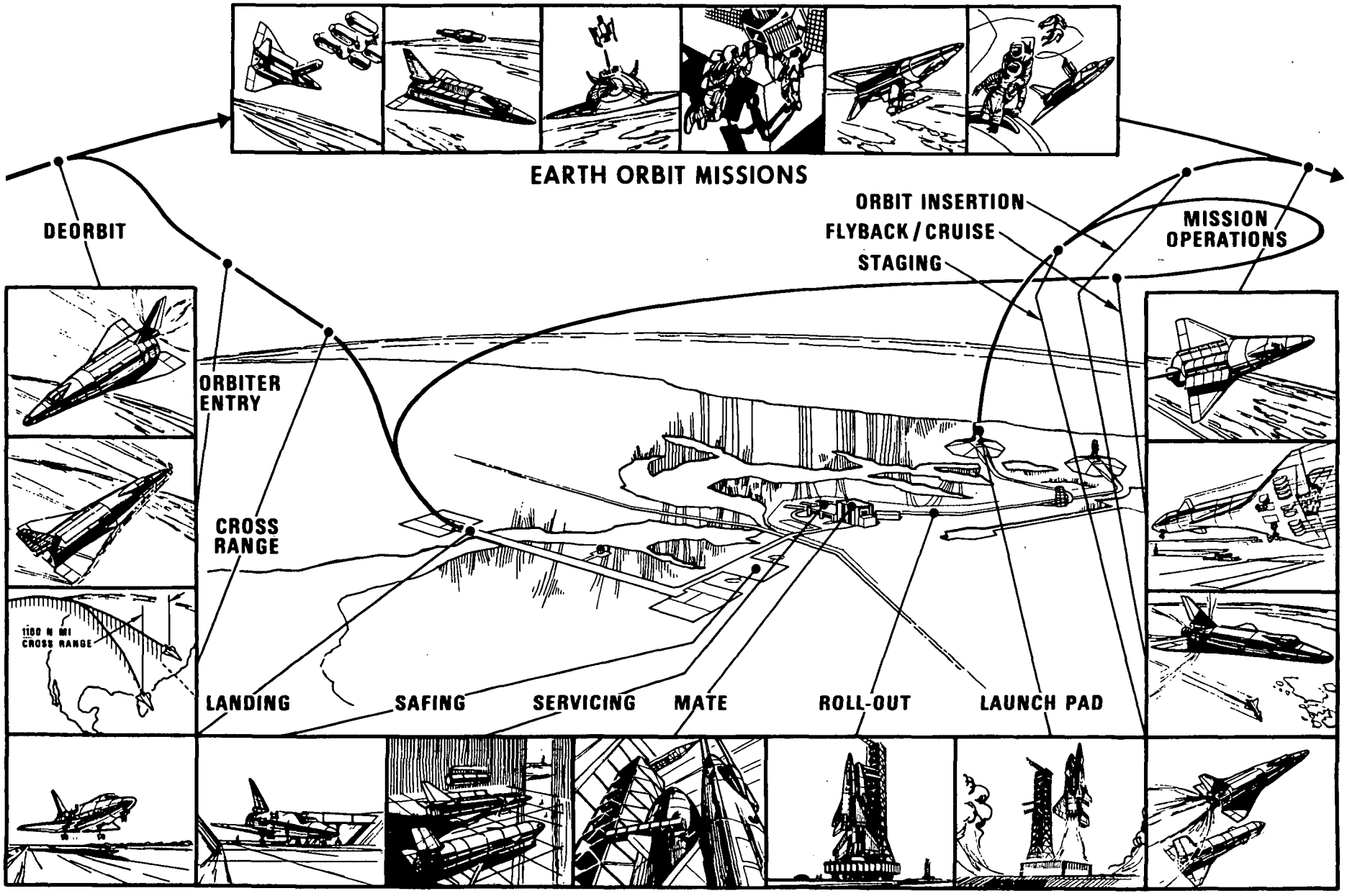






The booster and the orbiter are reusable delta-wing vehicles. The booster is equipped with 12 main rocket engines, an external heat shield to withstand the temperatures of boost and suborbital entry, and deployable airbreathing engines for cruising back to the launch site. The orbiter is equipped with two main rocket engines, orbital maneuvering rocket engines, an external thermal protection system to withstand the temperatures of boost and orbital entry, and deployable air-breathing engines installed for specific missions. The operations facility will provide for preflight readiness checkout, payload installation, and launch control, as well as primary landing sites and facilities for vehicle turnaround and necessary servicing. Shuttle support equipment includes all equipment required to check out, service, handle, and launch the flight vehicles.

The significant elements of these missions, as shown in the following figure, are ground operations, launch, and staging of the two vehicles. After staging, the first stage (booster) returns to the launch area while the second stage (orbiter) attains the prescribed insertion orbit after a series of orbital maneuvers. The second stage (orbiter) then delivers or retrieves its payload, enters the atmosphere, acquires the landing site, and completes the approach and landing. Safing operations are completed on each vehicle at the landing area preparatory to the turnaround cycle ground operations. Subsequent to payload installation in the orbiter, the orbiter is mated with the booster, and the mated system is made operationally ready and transported to the launch area for a new mission.



Elements of Space Shuttle Operations

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1.0 INTRODUCTION

1.0 INTRODUCTION

The Facilities Utilization and Manufacturing Plan has been prepared to define the major new facilities and major government-owned facilities required for the development, testing, manufacture, and operations phase of the Space Shuttle Orbiter Program, and to identify the major manufacturing problems and proposed solutions. In developing this plan, emphasis has been placed upon maximum utilization of existing national resources, economical acquisition of new facilities, and thorough analysis of potential manufacturing problems.

The optimum implementation approach to facilitization and manufacture of the orbiter vehicle in the immediate future, as presented herein, is directly applicable to Phases C and D of the Space Shuttle Program.

The Facilities section of the plan is organized by the major divisions of effort: final assembly, detail fabrication, development testing, flight testing, operations, transportation, program management, and training. Each section includes a summary of studies conducted to identify site locations, major government-owned facilities required, major new facilities planned, and major equipment required. Where the need for new facilities was indicated, alternative approaches were explored to assure minimum impact upon program cost and schedule objectives.

Recommendations are given for all orbiter program site locations, and the selection rationale is explained. Utilization of the recommended sites is described in detail, including information such as environmental data, special facilities and equipment, and special handling capability.

Major equipment to be furnished by the government is listed. Major machine tools, fabrication tools, and major equipment for testing and operations are included. In addition, the estimated costs and the proposed locations for checkout, development testing, laboratory testing, and operations are given; and long-lead time facilities and equipment requirements are indicated.

The Manufacturing Technology section identifies major manufacturing problems, manufacturing concerns, and items causing substantial program impact. Identification of manufacturing problems is based on a comprehensive study of the manufacturing process during which a manufacturing flow and

build plan was developed. The manufacturing problems were analyzed by the trade study technique to develop the optimum solutions. From this preplanning, manufacturing requirements for special tooling, material and personnel handling, parts-protection, and support equipment have been determined.

2.0 FACILITIES

2.0 FACILITIES

Facilities planning for the Space Shuttle Program begins with site evaluation and site selection.

Site evaluation was conducted with emphasis on major sites as components of a complete site sytem. It was recognized that site interrelationships impact and are impacted by transportation requirements, program management and control, operational liaison, and manpower requirements as well as by facilities requirements. The optimum site system should minimize long-haul transportation and barging of major assemblies between sites; should constrain the total number of sites to a readily manageable level; should maximize rapid and effective liaison, particularly with respect to management and engineering liaison with final assembly operations; and should maximize utilization of existing human resources. These considerations require an optimum balance between utilizing existing resources and avoiding excessive demands on individual site capabilities, including human resources. In addition, the impact of program termination on the site community must be considered. All these factors were evaluated within the framework of maximum utilization of existing national resources. Sites were evaluated both on an individual basis and on a site system basis.

Initially, a large number of locations throughout the continental United States were considered candidates for major Space Shuttle Program activities. The number was substantially reduced by eliminating those sites with obvious major disadvantages individually and as part of the total site system. Further reductions resulted from methodical elimination of candidates based on comparisons of major candidate site features. A small number of highly qualified sites remained for detailed analysis and comparison.

Final assembly facility candidates chosen for detailed analysis are Kennedy Space Center, Michoud assembly facility, Seal Beach assembly facility, and Tulsa assembly facility. Numerous sites also were considered for major subassemblies, and rationale for recommending their selection is included in this document.

Development test facilities for planned major tests require a high degree of specialization. Sites are recommended for each type of testing. For horizontal flight testing, three primary candidates, Edwards Air Force Base, Eglin Air Force Base, and KSC are considered. Rationale for site selection and utilization is described.

Launch operations candidates were reduced to six for detailed analysis: Clinton-Sherman Air Force Auxiliary, Oklahoma; Edwards Air Force Base, California; Holloman Air Force Base, New Mexico; KSC, Florida; Wendover Air Force Auxiliary, Utah; and the Western Test Range (Vandenberg Air Force Base), California. Selection rationale and initial facilities costs for each site were developed.

It is planned to use government-owned facilities available through enabling contracts, government-owned facilities utilized by contractors on a shared basis, and contractor-owned facilities. The co-use of government-owned facilities will be on a noninterference basis with existing government work; however, it is assumed that these facilities will be available as required by this plan. Where joint use is required with other contractors, methods of utilization will be established to meet program objectives.

The overall facility utilization plan recommended by North American Rockwell is as follows: Final assembly of the orbiter will be performed at the Seal Beach assembly facility, which has immediate access to the existing NASA Seal Beach tank fabrication facility. The forward fuselage with its integral LH_2 tank will be assembled at the NASA Seal Beach facility, and the crew module will be assembled at the NASA Apollo CSM assembly facility in Downey. The aft fuselage, which requires greater overhead clearance will be assembled in the VAB at Seal Beach, subassemblies will be provided from NR's Columbus Division, and the intermediate fuselage will be manufactured in sections at USAF Plant No. 3 at Tulsa. Major assemblies, such as wings and stabilizers, will be built by subcontractors and shipped by air to the nearby Long Beach Airport. The intermediate fuselage will be shipped by air in a disassembled configuration; and the fully assembled orbiter vehicle will be barged 65 miles from the Seal Beach Navy Dock to Point Mugu, California, for preflight testing. It will then be flown 80 miles to Edwards Air Force Base, where the flight test program will be conducted. On completion of the flight test program, the orbiter will be flown in a series of ferry flights to KSC, the recommended launch operations center.

2.1 FINAL ASSEMBLY FACILITIES

Selection of the orbiter final assembly and checkout facility is a major Space Shuttle Program consideration. Its location relative to the major subassembly facilities, engineering and program management facilities, and flight test and operational facilities will affect transportation, liaison, schedules, and total program cost.

2.1.1 Site Evaluation Considerations

NASA has emphasized the importance of maximizing utilization of existing national resources. These resources are identified as skilled

aerospace personnel, efficient functional organizations, operational machinery and equipment, and buildings and structures. This requirement is given major consideration in the evaluation of each candidate site for final assembly, horizontal flight testing, and operations. Because of the large number and variety of special skills required by the program, the availability of skilled aerospace personnel is of particular importance to final assembly operations. Figures 2-1 and 2-2 show the physical sizes of the vehicle and its major subassemblies, Table 2-1 is a summary of final assembly considerations, and Table 2-2 is a list of typical final assembly machinery and equipment required.

Following methodical analysis of more than 100 sites, four primary candidates for orbiter final assembly were identified: Kennedy Space Center, Florida; the Michoud assembly facility, Louisiana; the Seal Beach assembly facility, California; and USAF Plant No. 3, Tulsa, Oklahoma. These sites are compared in the following paragraphs in terms of buildings and structures, transportation; skilled aerospace personnel; and proximity to test sites, contractor headquarters, and major assembly sources.

Buildings and Structures

The required physical dimensions of the buildings are based on the sizes of the vehicle and the areas required for safe handling of major assemblies. Mating of the vertical stabilizer establishes a lower chord height of 90 feet. Crane capacity of 15 tons in the final assembly area is dictated by the weight of the wings. Handling areas to locate and attach the wings establish a minimum bay width of 170 feet. Three in-line stations are recommended to support the schedule shown in Figure 2-3 which establishes an optimum building length of approximately 720 feet and a total building area, including low-bay support areas, of approximately 175,000 square feet. Floor loading capacity of up to 1500 psf is required with hard points for jacking. The localized building environment should be stabilized at ±10 F of the ambient building temperature. When environmental control is required for specific operations, localized portable enclosures can be used. Minimum exit door width should be 125 feet.

Support facilities, such as clean rooms for systems assembly, tube and wire harness fabrication facilities, metrology areas, tooling repair areas, electronic component staging areas, paint touchup capability, cribs, and offices are to be adjacent to the assembly building. Approximately 4000 square feet of air-conditioned area adjacent to the checkout station must be provided to house the integrated checkout equipment. Utilities distributed to the work areas should provide 100-psi filtered air, 3000 psi GN_2, as well as 480 and 120-volt ac (400-Hz) and 28-volt dc power. Primary power requirements are 6000 kva.

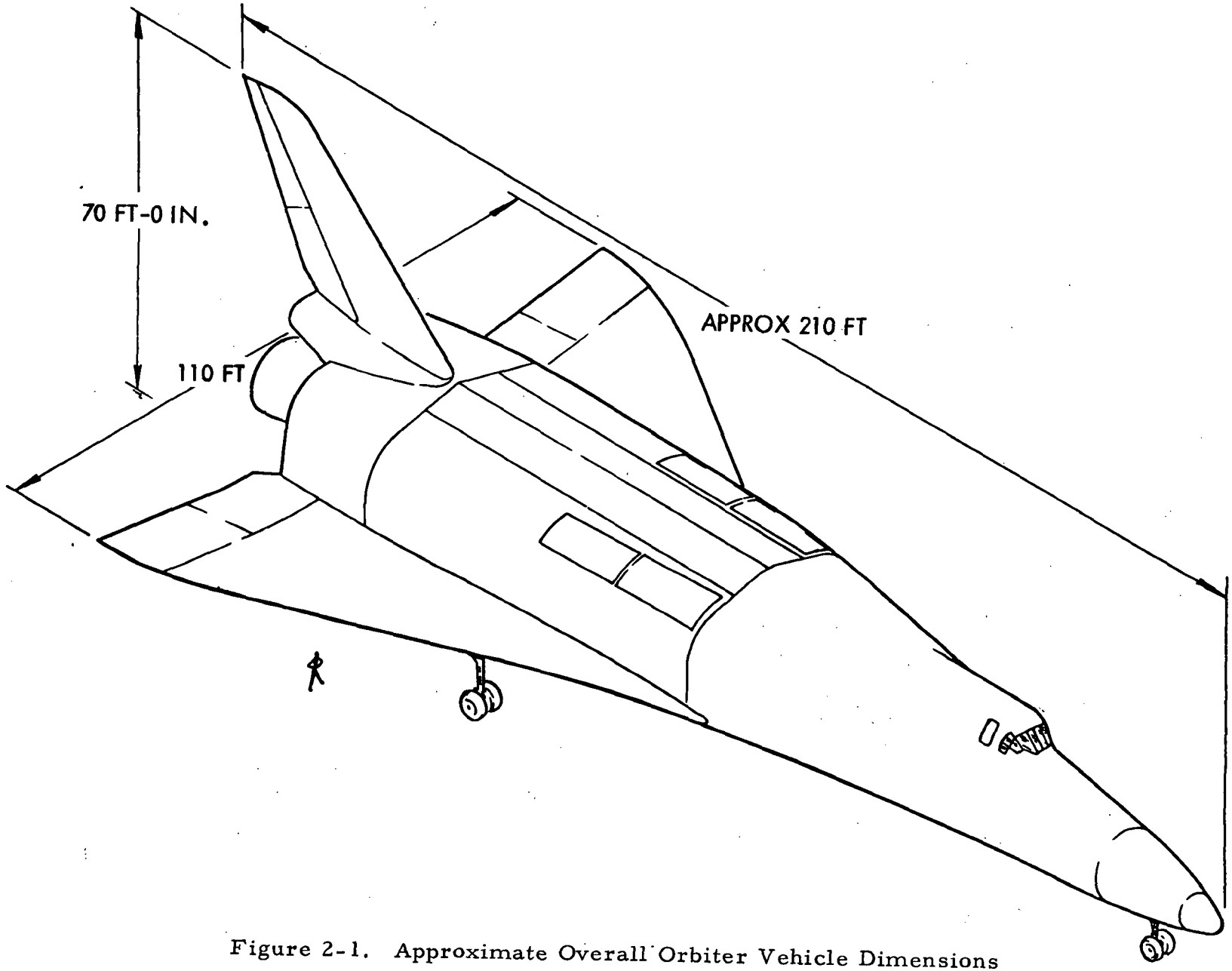

Figure 2-1. Approximate Overall Orbiter Vehicle Dimensions

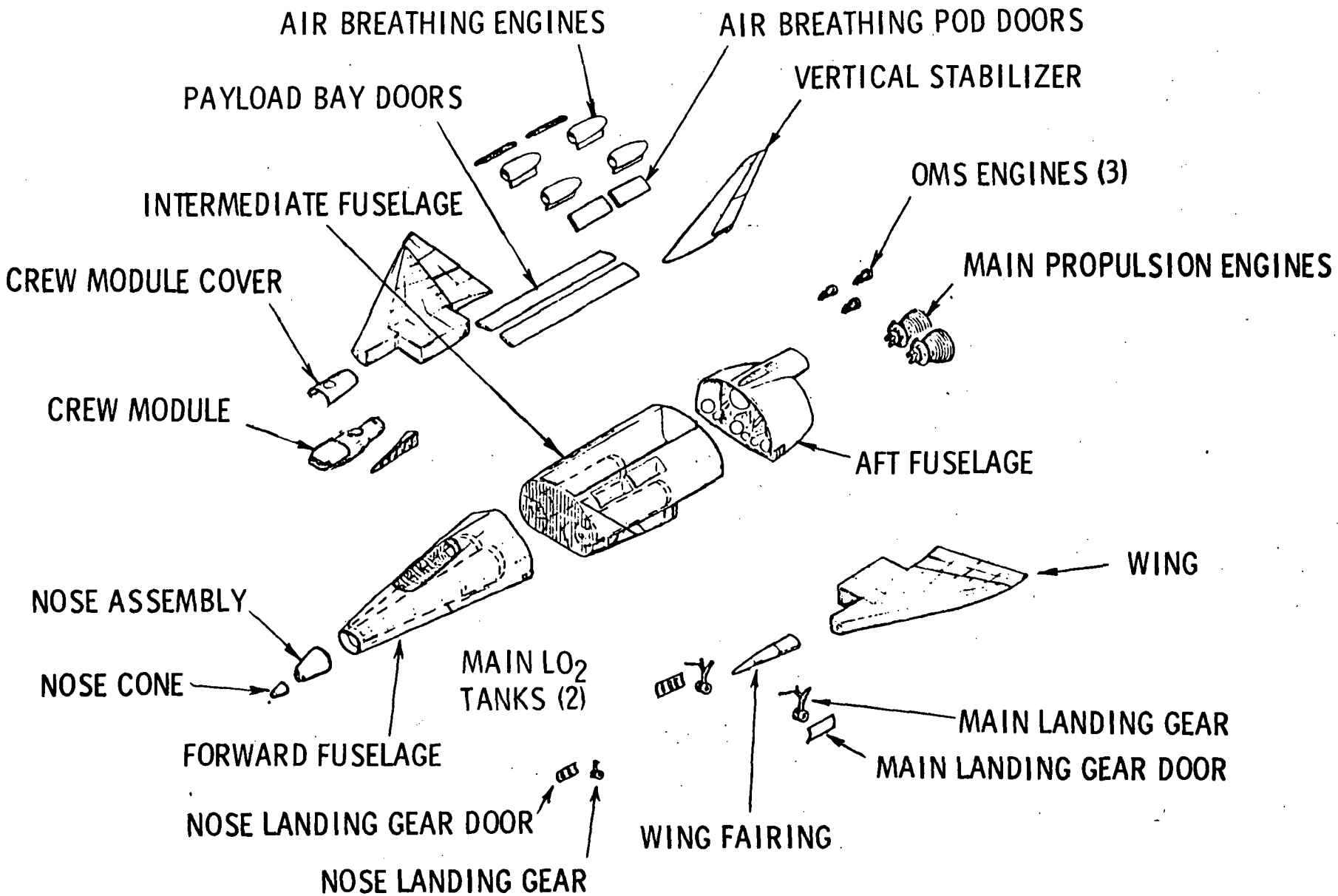

Figure 2-2. Orbiter Assembly Breakdown

Table 2-1. Final Assembly Requirements

Category	Requirements
Buildings and Structures	
Final assembly	Chord height -- 90 ft (mating of vertical stabilizer) Crane capacity -- 15 tons Bay width -- minimum 125-ft clear span plus 65-ft side access; or 170-ft clear span Stations -- three Area -- approximately 130,000 sq ft including support areas Floor loading -- 1500 psf Building environment -- ambient temperature stabilization to ± 10 F Doors -- 125 ft wide by 70 ft high Utilities -- 100-psi filtered air, 3000-psi GN_2, 5000 psi He; power: 480 and 120 volts ac, (400 Hz), 28 volts, 6000 kva primary Aprons and tow-ways Final assembly checkout
Support shops	Machine shop Electrical shop Hydraulics shop Engine buildup Landing gear buildup Production development laboratories Tooling
Office and Services	Area Proximity Computer access
Site layout	Consolidation and operational effectiveness
Availability	Must be available when required
Transportation	On-site roads On-site rail spurs Landing strip Water access Highways Railroads
Personnel	Management Technical Skilled labor
Proximity Factors	
Support	Suppliers and vendors Horizontal flight test Operations Contractor headquarters
Major assemblies	Tanks Fuselage sections Crew module

Table 2-2. . Typical Final Assembly Machinery and Equipment

1. Tow tractor
2. Workstands, 15 to 30 feet high
3. Hydraulic jacks, tripod type, to 50-ton capacity
4. Vacuum cleaning systems
5. Hydraulic power supply, 5000 psi
6. 115-volt 400-Hz power supply unit
7. GN_2 pressure supply unit
8. He pressure supply unit
9. Automatic circuit analyzer
10. Ground air-conditioning carts
11. Mass spectrometer and leak detectors
12. Electronic load-cell weighing set
13. Alignment instruments and stands
14. Tube bending equipment
15. Tube welding equipment
16. Tube weld X-ray unit and viewer
17. Miscellaneous nondestructive test equipment
18. Miscellaneous small machine tools and portable tools
19. Work benches and supply racks
20. Flushing pump units
21. Portable paint booth
22. Cooling units for GSE
23. Miscellaneous metrology equipment
24. TIG and MIG welders and brazing equipment

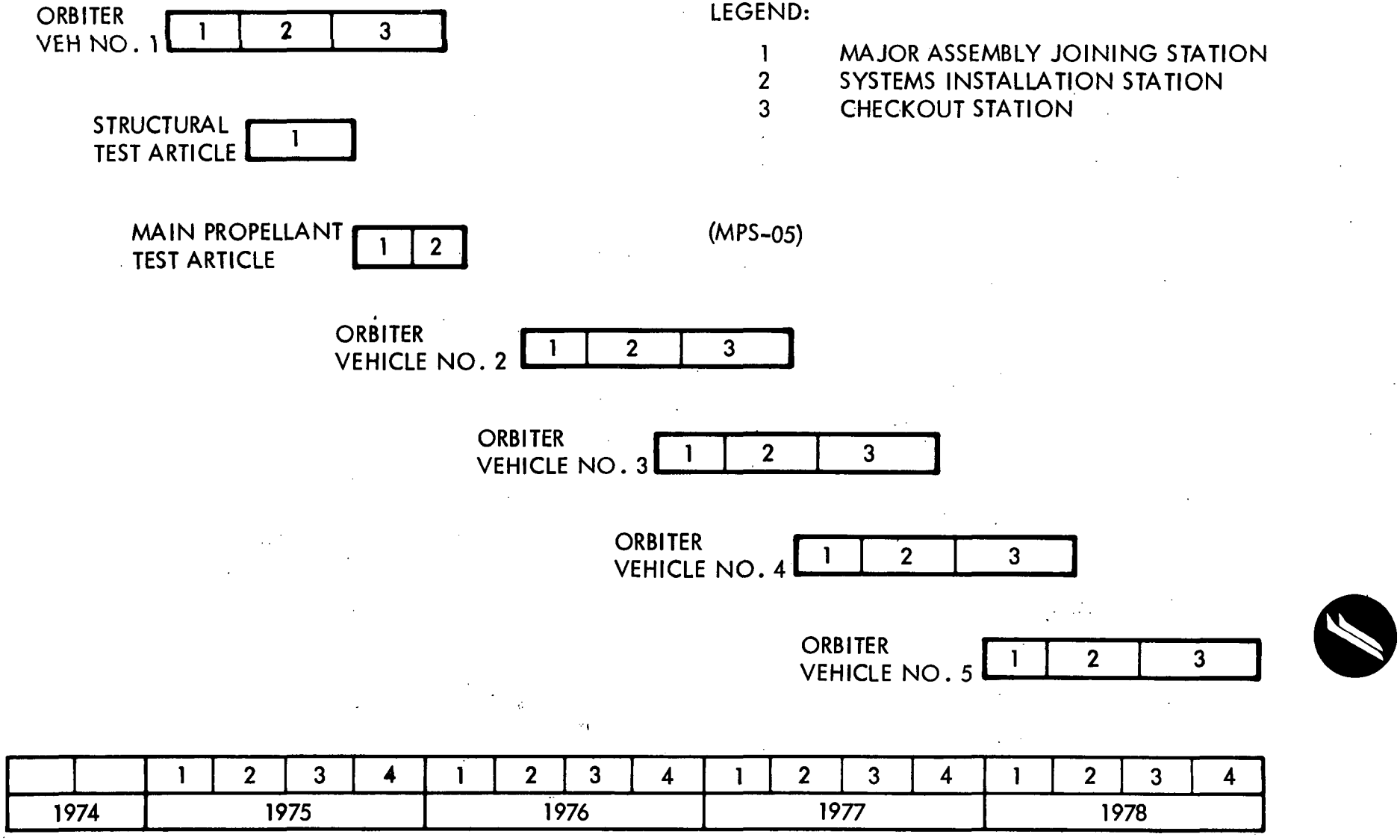

Figure 2-3. Schedule for Utilization of Three Final Assembly Stations

Transportation

Consideration must be given to the availability of air, water, rail, and highway access to the sites for incoming parts and subassemblies and outgoing completed vehicles. Distances from the major subassembly facilities and the sizes of subassemblies require accessibility to runways capable of Guppy-type aircraft operations or to barge and ship docks with handling capability for large structures. Shipment of completed vehicles may be accomplished either through direct fly-away or water-transport.

Support Shops

Electrical assembly shops and hydraulic shops are essential, as are specific shops for engine and landing gear buildup. Production support laboratories are also required. Specialized machinery and equipment needed for final assembly and checkout operations such as minor tool maintenance equipment, continuity-check equipment, workstands, jacks, alignment instrumentation, tow tractors, etc., are identified in Table 2-2.

Personnel

The availability of skilled, experienced personnel with aerospace assembly, management, and technical skills is a major requirement.

Proximity Factors

Ready access to suppliers and vendors is an important requirement. In the interest of schedule maintenance, engineering and technical personnel of the suppliers should be readily available for troubleshooting and modification efforts. A large aerospace-oriented industrial base should be accessible to the assembly site.

Various flight test facilities across the country are available to each of these sites; however, consideration should be given to the distances involved and whether first flight must be from the assembly site or from the flight test facility itself.

Other distance considerations include potential sharing of facilities for operations requirements, advantages of combining final assembly operations with contractor headquarters, proximity of vehicle structural testing facilities, and proximity of major assembly sites.

The following subsections summarize evaluation of the four primary candidate final assembly sites.

2.1.2 Kennedy Space Center

Consideration of KSC, Florida, as the orbiter final assembly site is based on its use as the launch and operations site. It is capable of accommodating final assembly, horizontal flight testing, launching, and operations at a single site. The NASA facilities on Merritt Island and the Air Force facilities on Cape Kennedy afford support for the orbiter final assembly effort.

Buildings and Structures

The KSC Vertical Assembly Building (VAB) located in the Launch Complex 39 area (Figure 2-4) is the building most suitable for orbiter final assembly. It provides the necessary height and floor area for required operations and has four high-bay areas, each with approximately 28,000 square feet of usable floor area. Doors to the high bays are 149 feet wide, providing adequate clearance for a completely assembled orbiter vehicle. The low-bay area, 60,000 square feet, is suitable for manufacturing operations required in direct support of final assembly operations.

A central transfer aisle extending the full length of the VAB has sufficient height and width (92 feet) to accommodate one assembly station excluding wings. The high-bay area, including the transfer aisle, has 250-ton bridge crane coverage throughout; the low bay has a 175-ton bridge crane with 165-foot hook height.

Two of the high bay areas in the VAB would be required for final assembly operations, leaving one for shuttle mating operations and another for other NASA programs. Initial joining of major sections of the fuselage could be accomplished in the transfer aisle and subsequent final assembly and checkout operations could be accomplished in two adjacent high-bay areas as illustrated in Figure 2-5.

As final assembly operations phase out, area in the VAB could be reassigned for mating and checkout and for ground operations as described in Section 2.5 of this plan. Localized modifications will be required for environmental controls and air-conditioning and/or ventilating systems.

Special facilities, such as GN_2 and He supplies utilized on other programs have the capacities required for orbiter checkout. Checkout equipment could be located immediately adjacent to the final assembly stations. A central computer complex (9030 square feet) on Merritt Island can provide necessary support for planned final assembly and checkout operations. Primary and secondary power, water, and shop-air utilities are also suitable for final assembly operations with very minor modifications.

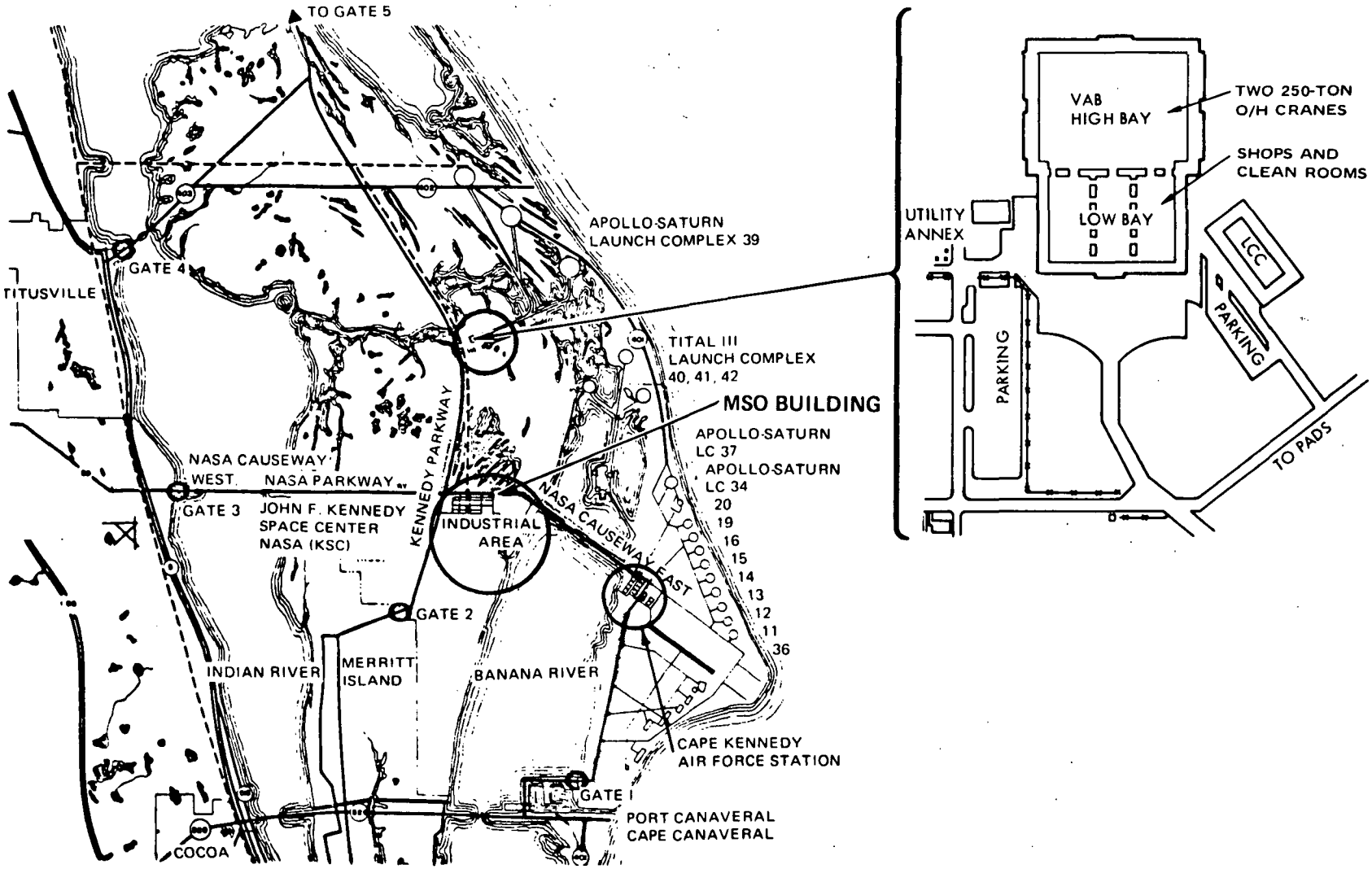

Figure 2-4. KSC Complex

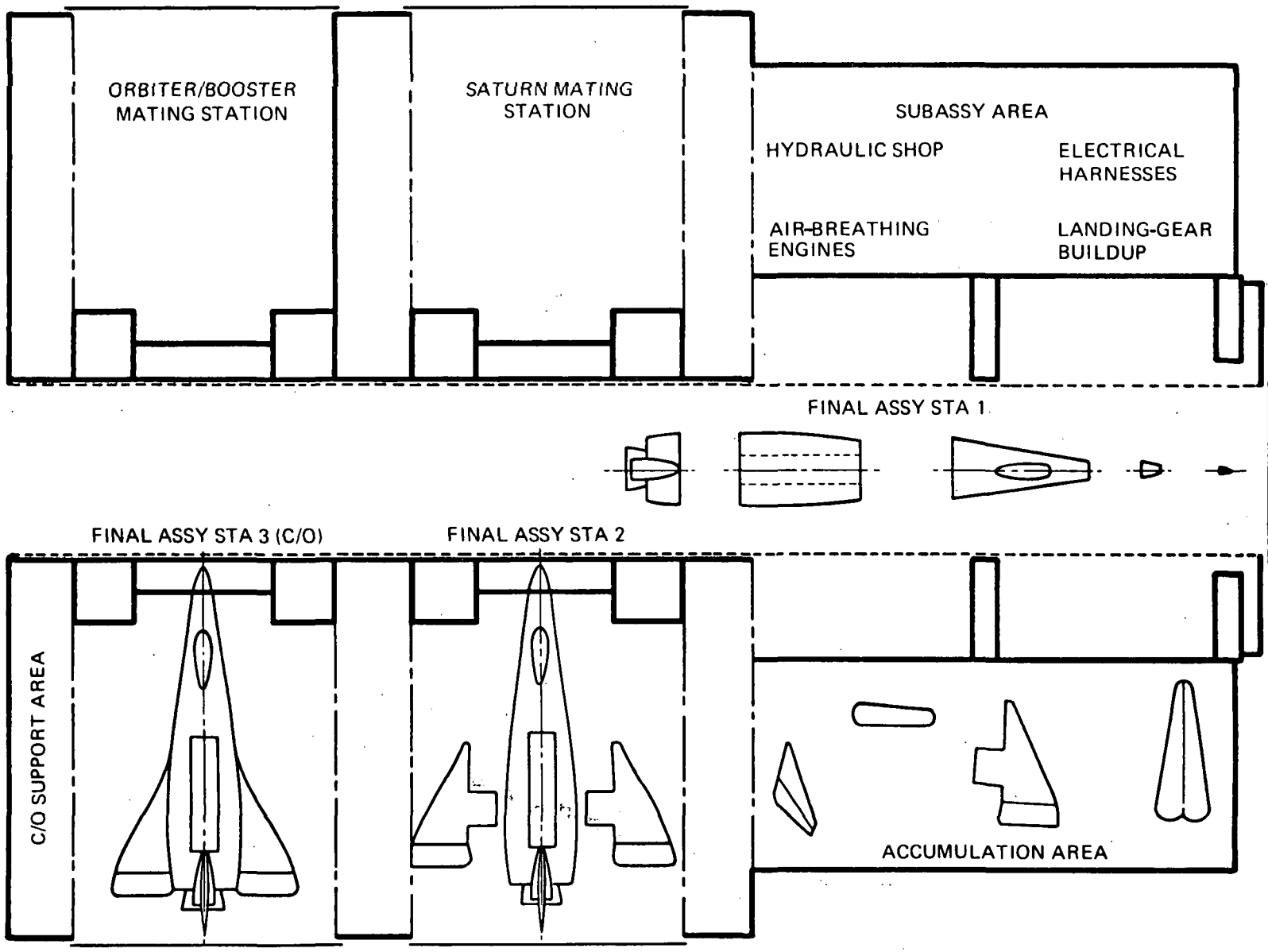

Figure 2-5. Utilization of KSC VAB for Final Assembly

Many other buildings and facilities with potential application to support final assembly operations are situated in the KSC industrial area and in the Cape Kennedy Air Force Station area to the east. The base support building (84,000 square feet) houses maintenance shops, sheet metal, welding, and other maintenance support shops. A warehouse includes area for spares, bonded warehousing, and a staging area (500,000 square feet), 40 percent of which is air conditioned. The 440,000-square-foot headquarters building in the industrial area provides heated and air-conditioned facilities for administration, program management, engineering, and associated support functions.

Buildings at the Cape Kennedy Air Force Station that could have application to orbiter final assembly include the 41,000-square-foot Missile Assembly Building M, the 81,000-square-foot Missile Assembly Buildings R and D, the 61,000-square-foot Missile Assembly Building S, Spacecraft Assembly and Checkout Building AE, the 27,000-square-foot Unmanned Spacecraft Building AM, the 44,000-square-foot Spacecraft Building AO, the 54,000-square-foot Engineering and Laboratory Building, and the 66,000-square-foot Hangar AF.

Existing launch-oriented shops and laboratories are widely diversified and abundant at both industrial complexes, and many would have application to final assembly. Support functions requiring very close direct liaison and coordination with final assembly could be located in the office and support areas on various floors of the VAB. Other functions could be located at the MSO Building and other buildings on the NASA and the USAF sites provided that interference with other on-going programs, NASA requirements, booster assembly requirements, and operations requirements can be avoided.

Transportation

Utilization of KSC both as the orbiter final assembly site and as the launch and operations site would reduce transportation problems associated with the completed vehicle to the minimum. Transportation of assemblies and components too large to be shipped by air, truck or rail could be barged to the site.

The site has its own barge terminal for transport of space vehicle stages and large assemblies. It has an access canal with a 1200- by 1200-foot turning basin, 1200-feet of docking frontage, and is maintained at 10-foot depth. Hard-surfaced roads extend from the turning basin to the VAB and other areas in the complex. The site is served by a system of interconnecting roads with access to the interstate highway system and by an on-site rail spur. Air shipments can be received at the existing 10,000-foot Cape Kennedy AFS skid strip that accommodates aircraft of Super Guppy and comparable size. A new airstrip planned for ground operations of the

shuttle program, constructed early, could be used for incoming subassemblies and components.

Machinery and Equipment

Machinery and equipment at KSC consists predominantly of laboratory support equipment for special-purpose use. At the KSC industrial site and at the Air Force site, support shops exist for light-machining of patterns and plastics, plating, welding and heat treating, sheet metal work, aerospace ground equipment repair, and instrument repair and calibration. Support available from existing shops could be utilized as appropriate, particularly to fabricate final assembly production aid tooling.

Skilled Experienced Personnel

Functions at KSC to support space launching are applicable to support of final assembly operations. It would be necessary to relocate key management and lead technical personnel from the contractor's headquarters with most of the technical skills required to be obtained from local sources.

Location of orbiter final assembly at KSC provides an opportunity to effect management and operational efficiencies through use of a single site for all program phases.

Proximity to Suppliers and Vencors

Local supplier support for manufacturing requirements is minimal. Some support of pertinent nature is located in Atlanta, Georgia, some 300 miles away. Additional support could be obtained from the Jacksonville, Miami, and Tampa areas.

Proximity to Flight Test

Utilizing KSC as the operational base as described in Section 2.5 and providing early construction of an operations airfield would permit horizontal flight test to be performed at the site.

2.1.3 Michoud Assembly Facility

The 897-acre Michoud facility, 15 miles east of New Orleans, is a primary candidate for final assembly because the Government-owned engineering, fabrication, and assembly facilities exist and are operational and available. The site is served by highway, rail, and a navigable waterway suitable for barge transportation.

The NASA-operated Michoud Facility provides approximately 3,500,000 square feet of building area. Approximately 2,000,000 square feet are dedicated to manufacturing, 752,000 square feet to office, 200,000 square feet to laboratories, 314,000 square feet to warehousing, and 135,000 square feet to supporting activities (Figure 2-6).

Buildings and Structures

The manufacturing building (Building 103) has a total of 1,978,000 square feet of floor space. It is 1,680 feet long and 1.095 feet wide. The main area has a uniform chord height of 40 feet. The building has two mezzanines; one, running the full length of the building, contains offices and support facilities. The rear of the building has a covered loading platform for rail and truck access. The entire building is environmentally controlled to a maximum dry-bulb temperature of 85 F and a maximum relative humidity of 60 percent. Certain areas within the building requiring lower temperature and humidities are equipped with separate air-conditioning systems. Plant electricity is provided through a 115-kv substation to two master substations with a capacity of 60,000 kva.

Orbiter final assembly operations could be accommodated in the manufacturing building, Building 103 (Figure 2-7). It would be necessary to add to the building to provide a 90-foot chord height. Portions of the final assembly floor require modification to sustain 1500 psf. New doors to the ramp are required and should be 70 feet high by 125 feet wide and 40 feet high by 50 feet wide. Existing bridge cranes, rated at 5-ton and 15-ton capacity, are adequate. The building also provides adequate shop and laboratory facilities to accommodate the final assembly operations. Secondary utility modifications are required for redistribution to points of use.

The stage test building (Building 420), situated some 500 yards southwest of Building 103, is equipped for automatic checkout of electrical, mechanical, hydraulic, pneumatic, and related systems. This five-story building has an area of nearly 109,000 square feet and houses four test cells, control rooms, computer rooms, telemetry rooms, offices, and support areas.

The administration building (Building 101) located on the north side of the site provides 90,000 square feet of heated and air-conditioned office space. Covered passages connect it with the adjoining two-story Engineering Building (Building 102), which provides 120,000 square feet of office space. A common wall separates the engineering building from Building 103.

An engineering and office building (Building 350) has an area of approximately 542,000 square feet. The contractor services building

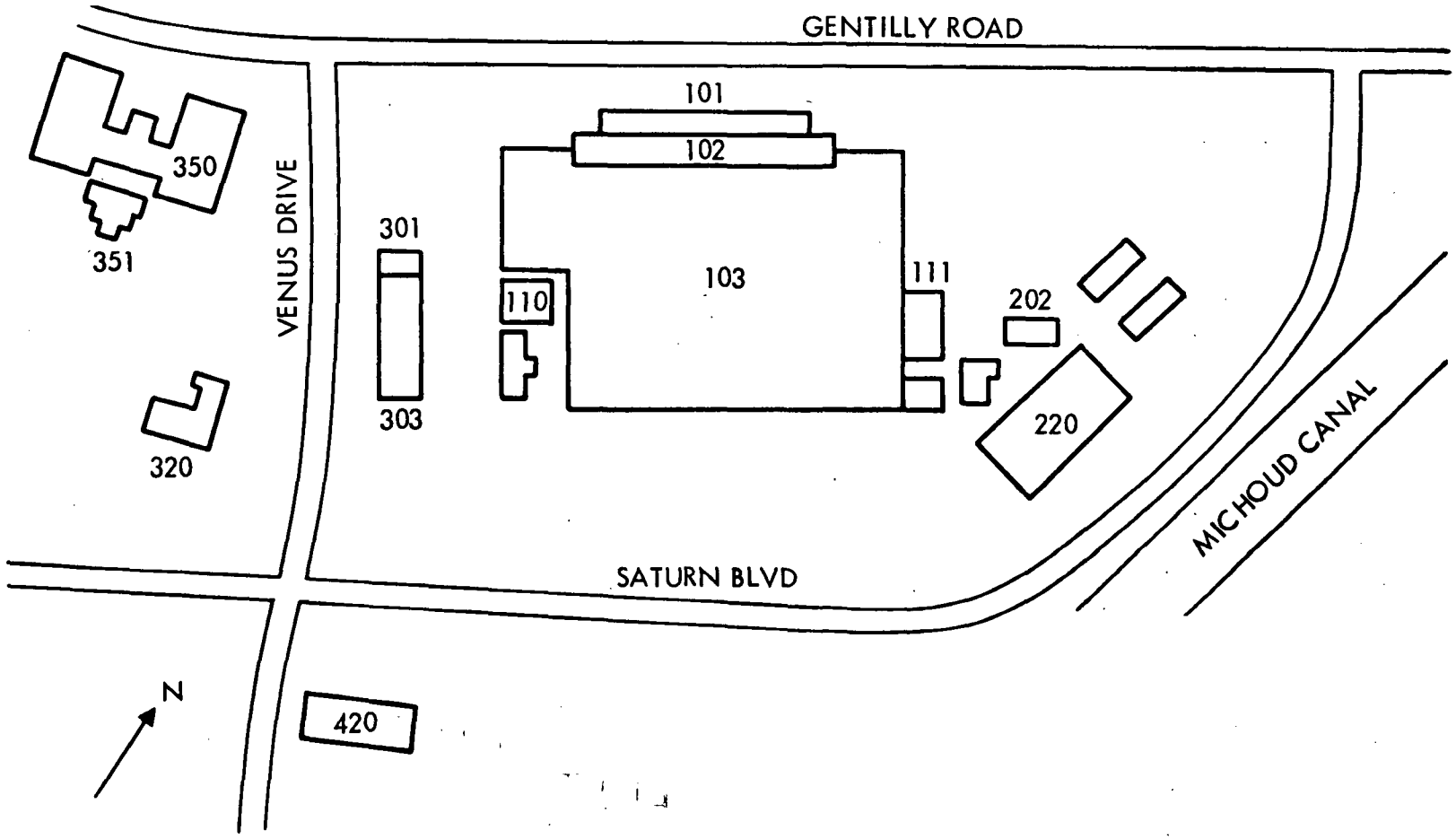

Figure 2-6. Michoud Assembly Facility

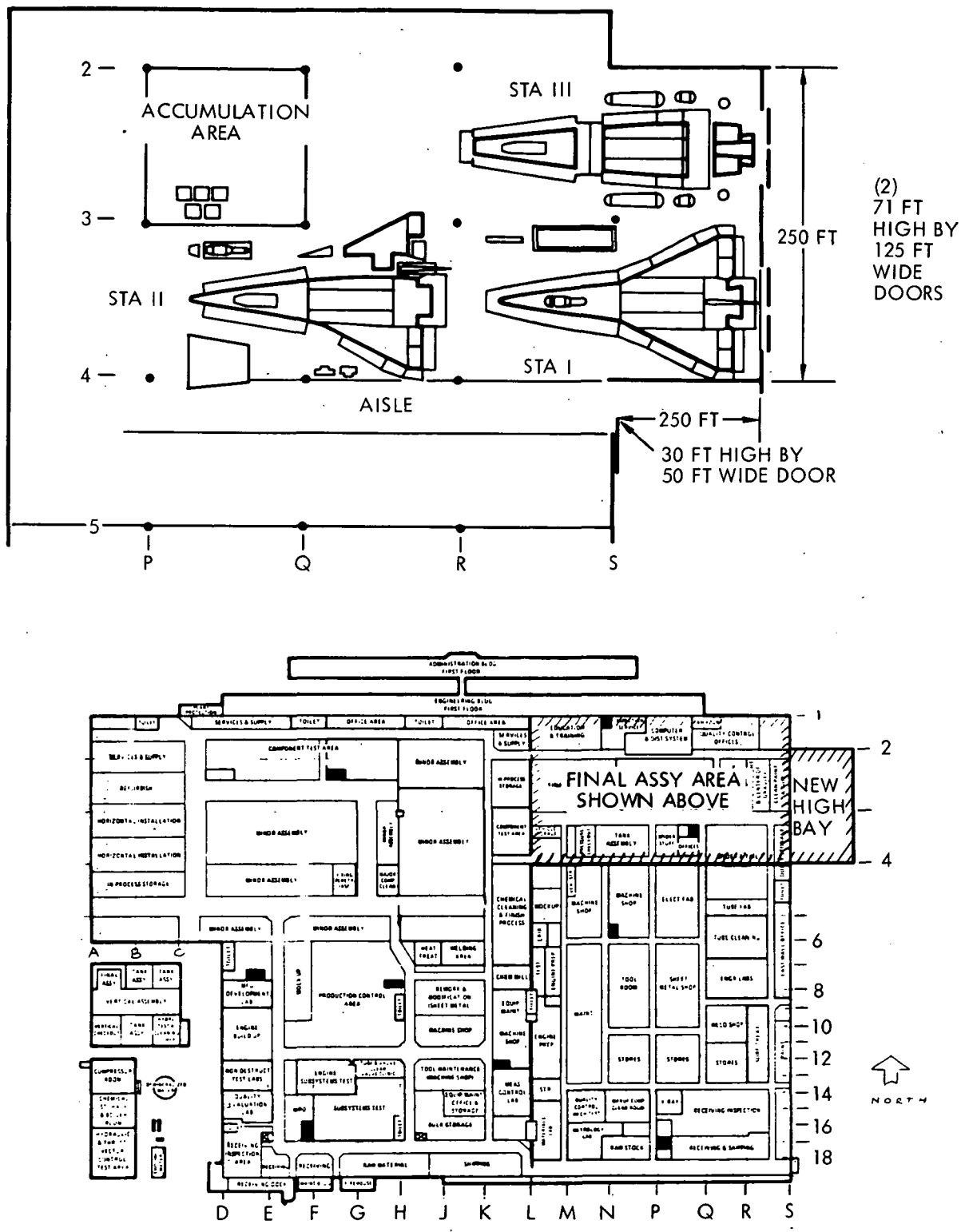

Figure 2-7. Utilization of Michoud Building 103 for Final Assembly

(Building 320), with an area of 84,000 square feet, houses medical, reproduction, communications, plant protection, transportation, and photographic functions.

Other facilities include Building 220, hardware storage, covering 200,000 square feet; a hazardous material storage building covering 18,590 square feet; Building 303, vehicle storage, covering 114,000 square feet; and a boiler house covering 29,268 square feet, which supplies heat and air conditioning to the manufacturing complex.

At Slidell, Louisiana, 23 miles from the Michoud Assembly Plant, the 110,000-square-foot Slidell Facility provides all computer support for the Michoud Plant. In evaluating candidate sites, this NASA facility, supporting both the Michoud Plant and the Mississippi Test Facility, is considered to be part of the Michoud assembly complex.

Availability of required area at Michoud is contingent upon requirements imposed by other Space Shuttle activity at the site including booster tank and booster final assembly operations. These activities, in combination with orbiter final assembly requirements, may exceed plant capacity, particularly with respect to office area.

Transportation

The Michoud complex is supported by a system of major and minor roadways and a rail spur off the Louisville and Hashville main line. Rail spurs extend to the manufacturing area loading dock and to all warehouse areas. A dock, 600 yards west of the main plant within the Michoud slip, opens into the intracoastal waterway. A 75- by 200-foot concrete dock built on concrete piling includes two mooring wharves, a 2,400-square-foot prefabricated metal storage building, lighting, and utility systems.

Incoming major assemblies would utilize water transportation for those cases in which size constraints prohibit overland or air transportation. Transportation of the orbiter vehicle from the final assembly plant at Michoud to horizontal flight test at Eglin or KSC can be accomplished by barge, AKD, or similar sea-going vessel. At KSC, the locks would require extensive modification to accommodate vessels large enough to transport a complete orbiter vehicle.

There is no airport accessible to the Michoud Plant to permit fly-out of the completed orbiter.

Machinery and Equipment

The Michoud Assembly Plant is equipped with the types of machinery and equipment required to support final assembly operations. There is suitable capability for production aid tool fabrication and for any rework or modification to subassemblies and tooling as required during final assembly operations.

Skilled Experienced Personnel

The New Orleans area has aerospace management personnel with experience in aerospace fabrication techniques obtained through assembly of Saturn boosters at the Michoud Assembly Facility. Technical craftsman with similar program experience are also available in the area. It would be necessary to relocate key management personnel from the contractor's headquarters.

Proximity to Suppliers and Vendors

Most major industries within the immediate region are not aerospace oriented. The plant is accessible via major transportation systems to the greater Atlanta, Jacksonville, Dallas and St. Louis areas for necessary support.

Proximity to Flight Testing

Transportation of a completed orbiter vehicle requires an extended barge trip from the Michoud dock to a new dock facility required at Eglin Air Force Base or to KSC for horizontal flight testing.

2.1.4 Seal Beach Assembly Facility

The NASA/NR Seal Beach site was considered for orbiter final assembly primarily because of its proximity to this contractor's management, engineering, and production base and because it offers the opportunity to utilize Southern California national aerospace resources to the maximum. This site was designed and built for assembly of the Saturn S-II stage and is ideally suited to the fabrication of large tank assemblies. Additionally, it has the capability for transportation of large vehicles as demonstrated by shipment of the S-II stage from this site.

The master site plan for the development of the NR-owned portion of the site includes a major NR-funded assembly building suitable for orbiter final assembly. Site grading has been completed and utility installations meet requirements of this plan (Figure 2-8).

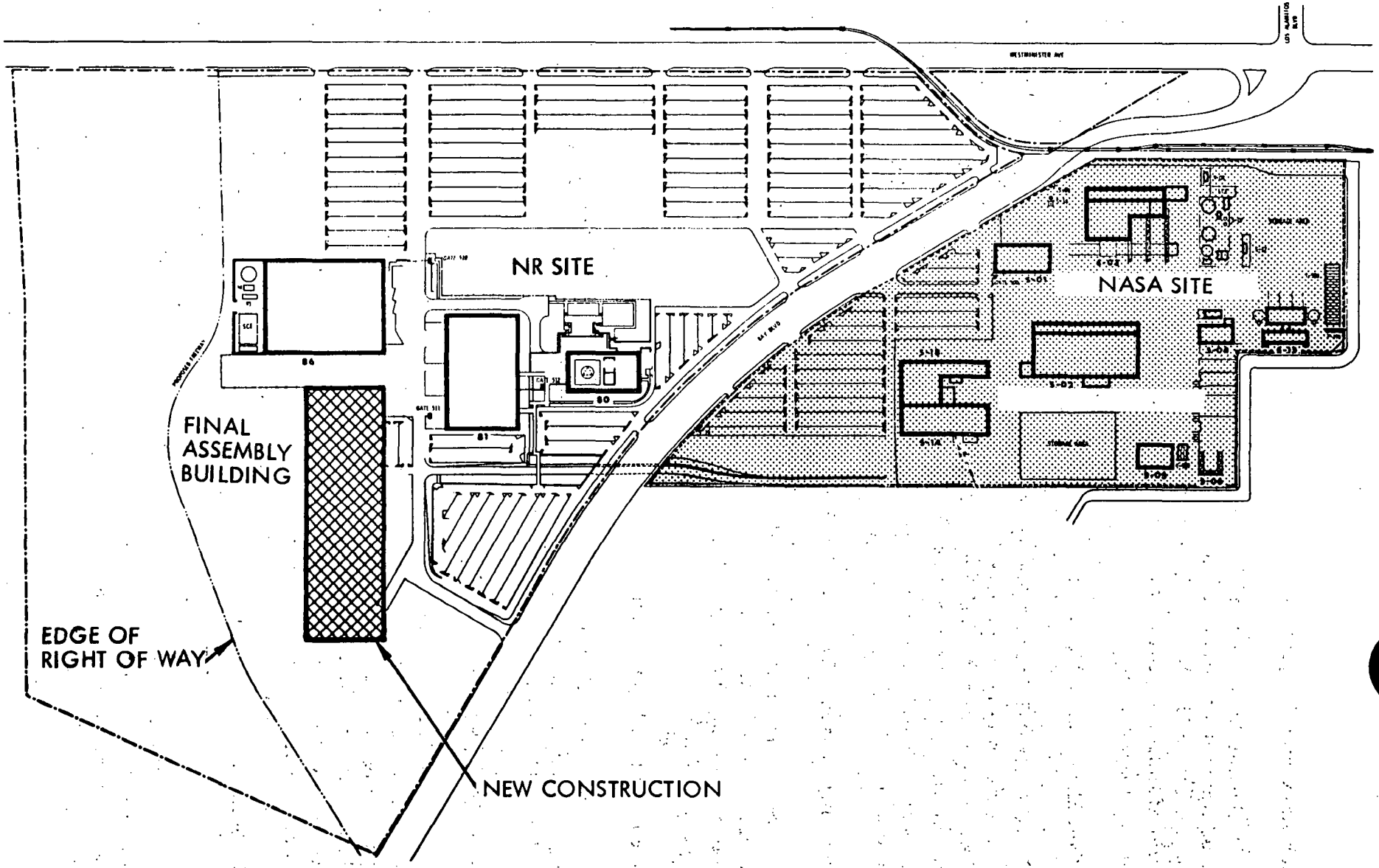

Figure 2-8. Seal Beach Final Assembly Facility

The NASA site consists of 40.1 acres with seven major buildings providing 418,000 square feet of manufacturing, engineering, test, and support areas. The NR site consists of 124 acres with three existing major buildings, providing over 700,000 square feet of management, engineering, support, and warehouse area.

Buildings and Structures

The proposed final assembly building shown in Figure 2-9 will consist of 144,000 square feet of high-bay area with a lower chord height of 90 feet and a clear span of 200 feet, providing adequate clearance for all final assembly operations including movement of major subassemblies and the completed vehicle. A 15-ton bridge crane will be installed, and the doors will be 200 feet wide at each end of the building. The building will be stabilized at ± 10 F of ambient building temperature. An adjacent lower bay with a height of 32 feet, ground floor area of 63 by 720 feet, and a full mezzanine will be used for manufacturing support activities closely associated with the high-bay operations. It will include selected engineering functions, light manufacturing operations, checkout equipment, and other equipment. Checkout operations will be accomplished in the final station with equipment immediately adjacent to the checkout station. Utilities and special services will be distributed to the work areas at column bases and by floor trenches. These services consist of 100-psi filtered air; 3,000-psi GN_2; 5,000-psi He and 480 volts, 120 volts and 20 volts ac (400 Hz), and 28 volts dc secondary power.

Existing office area at Seal Beach of over 570,000 square feet adequately supports the orbiter final assembly operations requirements. The combination of this area with the Space Division area at Downey provides sufficient area for the entire orbiter program in a contiguous grouping.

The Seal Beach administration building (Building 80) is an eight-story, air-conditioned office and support building with a cafeteria, an auditorium, and an enclosed raised dock. Total area enclosed is 295,000 square feet.

Immediately adjacent to the administration building is the engineering laboratory and office building (Building 81), a three-story structure with 275,000 square feet occupied by engineering, research, and development laboratories and support functions. The Space Division Computing and Data Processing Center, located in company-owned Building 004 in Downey, provides service to Seal Beach through the use of terminal equipment connected by leased direct line to Downey.

The single-story warehouse and maintenance building (Building 86) has 136,000 square feet and is equipped with a 5-ton 25-foot-hook-height bridge

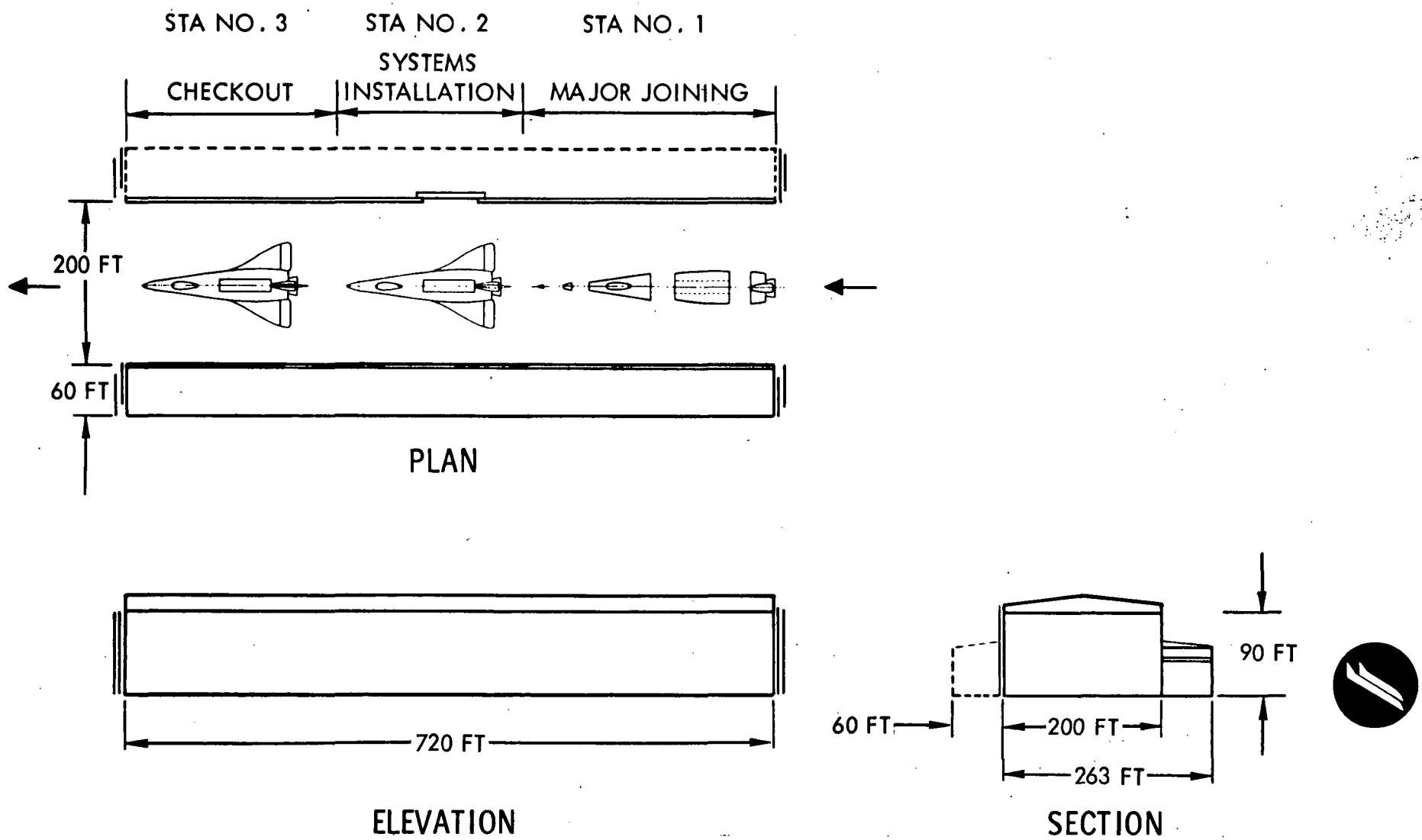

Figure 2-9. Final Assembly Building Concept, Seal Beach

crane, support services for the entire Seal Beach site, covered loading dock with truck well, and the main power substation for the NR site.

Transportation

The Seal Beack final assembly site is accessible for incoming parts and major subassemblies by roads, air, water, and rail. These transportation modes were established and utilized in support of Saturn S-II Program. Completed orbiter vehicles can be moved from final assembly by surface roads, approximately one mile, to the U. S. Navy Bureau of Ordnance dock for water transportation to Point Mugu NAS for flight to the NASA Flight Research Center at Edwards AFB for flight test. A new dock will be required at Point Mugu for this purpose.

Support Shops

The Seal Beach facilities are closely supported by the Downey (15 miles) and Los Angeles (27)miles facilities. The combined capabilities of the three facilities include production aid tool fabrication and rework or modification to subassemblies and tooling required during final assembly operations. The new building will include hydraulic and electrical shop facilities. Engine buildup and landing gear buildup shops will also be provided in the low-bay areas.

Skilled Experienced Personnel

The Southern California area has, as a primary national resource, the largest pool of aerospace management and technical personnel in the United States; therefore no significant personnel relocations would be required.

Proximity Factors

The NASA Flight Research Center at Edwards Air Force Base is readily accessible from the Seal Beach final assembly site. The completed vehicle can be transported by road to the Navy Dock at Seal Beach, then by barge to Point Mugu for preflight test. From there, the orbiter can be flown to the NASA Flight Research Center for final flight testing.

The Southern California area surrounding Seal Beach is the most complete supplier and vendor source in the Nation. It is capable of providing all major support required in conjunction with final assembly. In addition, colocation of final assembly with contractor headquarters can be achieved readily at Seal Beach since adequate area exists.

2.1.5 Tulsa Assembly Facility

The facilities located at the Tulsa International Airport, Tulsa, Oklahoma, are capable of supporting an orbiter final assembly operation. As shown in Figure 2-10, these facilities are U.S. Air Force Plant No. 3, the American Airlines Maintenance Base, and the NR-leased Mingo industrial buildings. This location, in addition to its 10,000-foot runway, has good access to transportation on the Arkansas River Waterway. Experienced assembly personnel and adequate machine tools to support final assembly are additional resources at this site.

Buildings and Structures

Air Force Plant No. 3 comprises 332 acres of land and 2,850,000 square feet of covered area. The main assembly building (Building 001) is 4004 feet long by 320 feet wide. Two main floor bays extending the length of the structure are 200 feet wide and 120 feet wide. There is also a 30-foot-wide mezzanine. The entire area is serviced by overhead crane hoists of 2-1/2, 5- and 15-ton capacity with a truss height of 40 feet. The hook height is 34 feet for the 2-1/2 and 5-ton cranes and 32 feet for the 15-ton crane. The building has 16 second- and third-floor mezzanines, 30 feet wide by 450 feet long. It is completely air conditioned and is equipped with service elevators and an automatic sprinkler system. The floor capacity exceeds 1500 psf. Forty-foot-high doors are 118.5 feet, 143.5 feet, and 195.25 feet wide. The first floor area totals 1,281,280 square feet; mezzanines add 216,000 square feet. Utilization of this building for final assembly of the orbiter as illustrated in Figure 2-11 would require increasing the truss height to 90 feet over 80,000 square feet of production area.

Other buildings at USAF Plant No. 3 are capable of supporting the orbiter assembly operations. The 300-foot by 153-foot paint hangar has 100 percent filtered air and doors 35 feet by 145 feet. The air-conditioned flight hangar is 854 feet long by 204 feet wide with a 40-foot chord height and an overhead handling system of 5-ton capacity. It is served by eight doors, 40 feet high by 195 feet wide. The first floor has an area of 171,914 square feet. The temperature-controlled engineering building adjoins the main assembly building. It houses the site's data processing, reproductions, publications, and communications services in 152,500 square feet of office-type area.

The Mingo industrial buildings, leased by North American Rockwell from the City of Tulsa, are located between Air Force Plant No. 3 and the American Airlines facilities. Buildings 604 and 605 have a total of 242,000 square feet of floor area with up to 26 feet of hook height under the

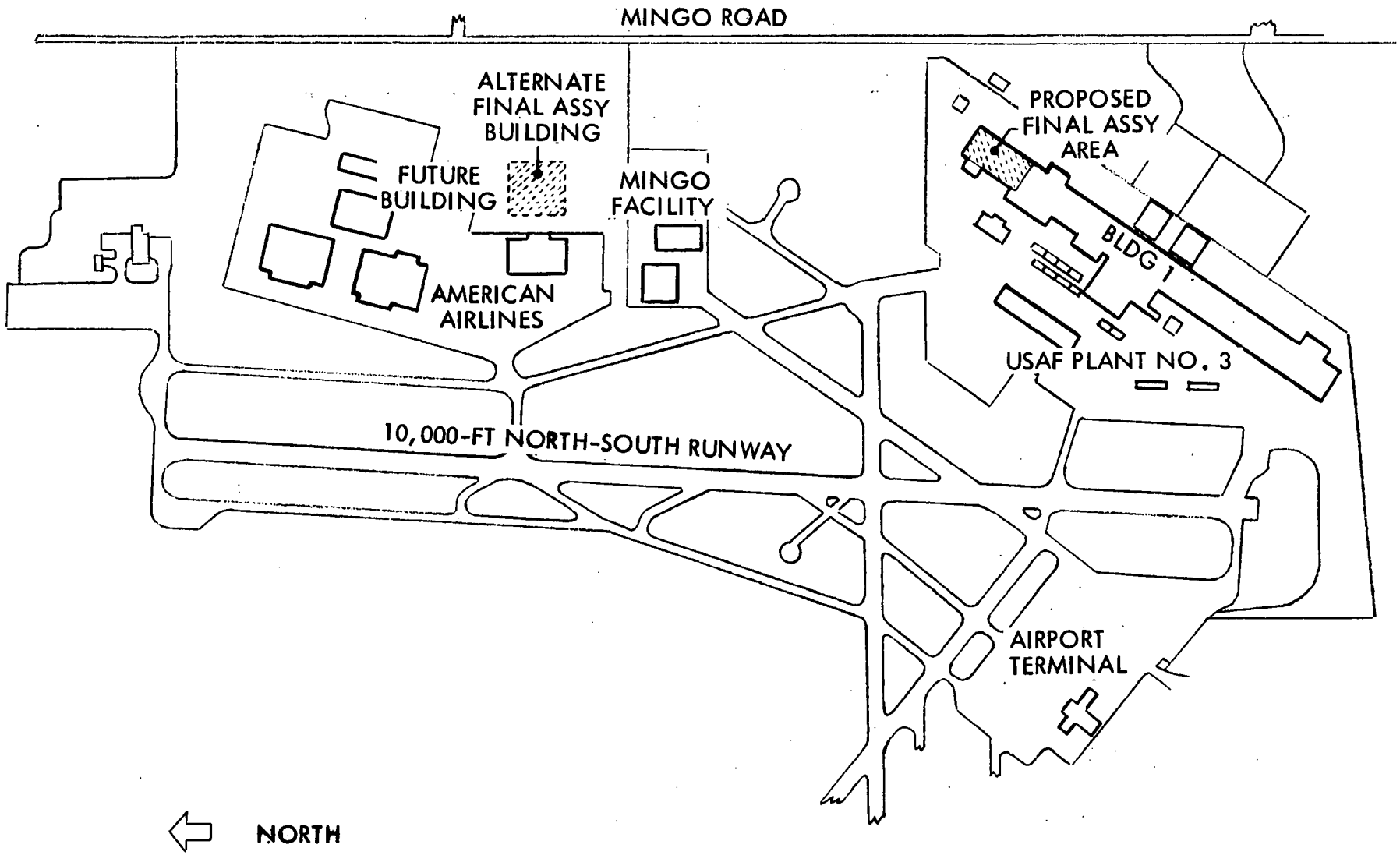

Figure 2-10. Tulsa International Airport

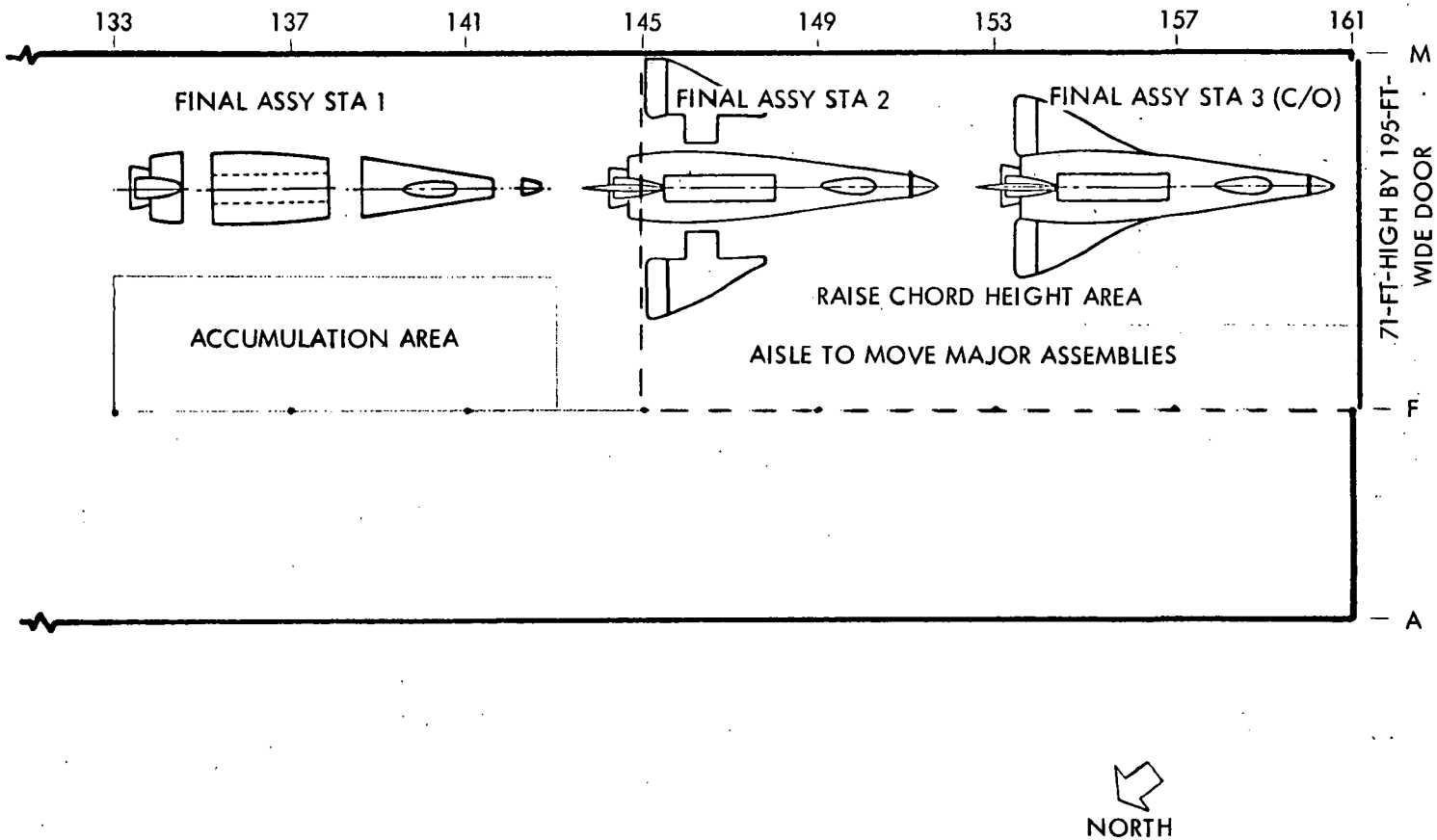

Figure 2-11. Utilization of Building 001, Tulsa, for Final Assembly

5-ton crane systems. Both buildings are temperature and humidity controlled. They provide subassembly and bonded structure buildup area.

The American Airlines maintenance and overhaul center adjoining the Mingo USAF Plant No. 3 complex provides an alternative to modification of the main building of Air Force Plant No. 3 through use of the 747 maintenance hangars. Preliminary discussions with American Airlines indicate the feasibility of early construction of one of the planned future hangars, which would provide 156,000 square feet with 90-foot chord height for orbiter final assembly. Upon completion of orbiter requirements for the facility, it would be returned to American Airlines. The building would be equipped with bridge cranes, utilities, and other support facilities in accordance with requirements established for orbiter final assembly.

Transportation

Transportation of completed orbiter vehicles from the final assembly plant to the horizontal flight test site would be accomplished by flying from the adjacent Tulsa International Airport. Preliminary discussions with Tulsa International Airport authorities have established the feasibility of obtaining local and FAA approval for initial flight operations from the airport.

Transportation of large subassemblies can be accomplished by air or by barge utilizing the Arkansas River barge channel to the Mississippi River. The Port of Catoosa, 9 miles from the Tulsa facility, is directly accessible by a four-lane highway designed specifically for the transport of large objects.

A rail spur of the St. Louis and San Francisco Railroad serving Air Force Plant No. 3 enters the south end of the main building.

Support Shops

The Tulsa plant is equipped with the major types of machinery and equipment required to support orbiter final assembly operations. Existing equipment is well suited for production-aid tool fabrication and for any rework or modification to subassemblies and tooling as required during final assembly operations. Shops for specialized work, such as engine buildup and landing gear buildup, are available although modernization is required. Other areas, such as electrical and hydraulic shops and production support laboratories, are available.

Skilled Experienced Personnel

The requirements for technical personnel to support orbiter final assembly can be filled from the existing pool of aircraft-type skills available

in the area. Certain managerial skills for this type of operation are also available; however, it would be necessary to relocate some key management personnel.

Proximity Factors

Suppliers, vendors, and major aerospace contractors in St. Louis, Dallas, and Kansas City, are reasonably close, and transportation from these sites is available.

Because of the availability of the Tulsa airport for preflight testing, proximity to a horizontal flight test site is not of great significance. Upon completion of preflight testing, the vehicle can be flown to any selected site.

2.1.6 Site Summary and Recommendations

A summary comparison of the four candidate final assembly sites is presented in Table 2-3.

2.1.7 Implementation of Recommended Final Assembly Site

Seal Beach is the recommended site for final assembly primarily because of the vast Southern California aerospace resources of management and technical skills, vendors and suppliers, and machinery and equipment. Within its aerospace divisions in Southern California, NR itself, has nearly all of the required machinery and equipment and fulfills the requirement for a functioning management team. The disadvantage of requiring a new high-bay assembly building is offset by the other outstanding attributes of this area.

Buildings and Structures

As stated previously, the facilities master plan for the NR Seal Beach site includes provision for a large manufacturing building. Underground utility systems, such as water, power, gas, sewage lines, and communications lines, were placed in easement patterns. Major site grading for the building and parking lot additions were planned and completed. Since the building is on NR property it will be provided by NR, minimizing government funding early in the program. As illustrated in Figure 2-9, the final assembly building high bay will be 200 feet wide by 720 feet long with an 85-foot chord height. It will accommodate three major stations for major joining, systems installation, and checkout. Manufacturing support activities will be located adjacent to the high bay. Figure 2-12 depicts the location and relative size of the building. The implementation schedule for this facility is shown in Figure 2-13.

Table 2-3. Final Assembly Site Comparison

Facility Considerations					
Category	Requirements	KSC	Michoud	Seal Beach	Tulsa
Buildings and Structures					
Final assembly	Chord height – 90 ft (mating of vertical stabilizer)	X	40 feet - Modification required	X	40 ft—Modification required
	Crane capacity – 15 tons	X	X	X	X
	Bay width – 125-ft clear span plus 65-ft side access; or 170-ft c. s	X	X	X	X
	Stations – three in-line	X	X	X	X
	Area – approximately 130,000 sq ft including support areas	X	X	X New building required to exact specifications	X
	Floor loading – 1500 psf	X	Modification required	X	X
	Building environment – ambient temperature stabilization ± 10 F	Modification required (addition)	X	X	X
	Doors – incoming: 50 ft wide by 40 ft high	149 ft wide; height OK	Modification required	X	Height increase required
	Outgoing: 125 ft wide by 70 ft high				
	Utilities—100 psi filtered air, 3000 psi GN_2, 5000 psi He; power: 480 and 120 volts ac (400 Hz), 28 volts dc, 6000 kva primary	X	X	X	X
	Aprons and tow-ways	X	X	X	X
	Final assembly checkout	X Add air conditioning	X	X	X
Support shops	Machine shop	USAF site	X	X	X
	Electrical shop	X	X	X In new building	X
	Hydraulics shop	X	X	X	X
	Engine buildup	USAF site	X	X	X
	Landing gear buildup	USAF site	X	X	X
	Production development laboratories	X	X	Seal Beach and Downey	X
	Tooling	USAF site	X	X	X
Office	Area	0.75 million sq ft	0.85 million sq ft	1.2 million sq ft (includes Downey)	0.15 million sq ft
	Proximity	X	X	X	X
	Computer access	X	X	X	X
Site layout	Consolidation and operational effectiveness	Support from USAF site	X	X	X
Availability		Share with operations requirements	X	X	X
Transportation	On-site roads	X	X	X	X
	On-site rail spurs	X	X	Extend adjacent rails	X
	Landing strip	Skid strip	No air strip	Available in Long Beach, 6 mi	Adjoins Tulsa airport
	Water access	On-site dock	On-site dock	Navy dock	Port of Catoosa
	Highways	X	X	X	X
	Railroads	X	X	X	X
Personnel	Management	Relocate key management	Relocate key management	X	Relocate key management
	Technical	Relocate lead technical personnel	Relocate lead technical personnel	X	Relocate technical personnel
	Skilled labor	Local sources plus transfers	Local sources	X	Local sources
Proximity Factors					
Support	Suppliers and vendors	Atlanta, Jacksonville, Miami, Tampa	Atlanta, Jacksonville, Dallas, St. Louis	Southern California sources	St. Louis, Dallas, Kansas City, Wichita
	Horizontal flight test	Adjacent	Barge completed vehicle	Barge completed vehicle	Flight from Tulsa Airport
	Operations	Adjacent	Not practical	Not practical	Flight strip permits overhaul
	Contractor headquarters	Remote	Remote	X	Remote
Major assemblies	Tanks	Remote	On-site	On-site	Remote
	Fuselage assemblies	Remote	On-site	On-site	Remote
	Crew module	Remote	Remote	Downey	Remote

X Indicates facility meets requirements.

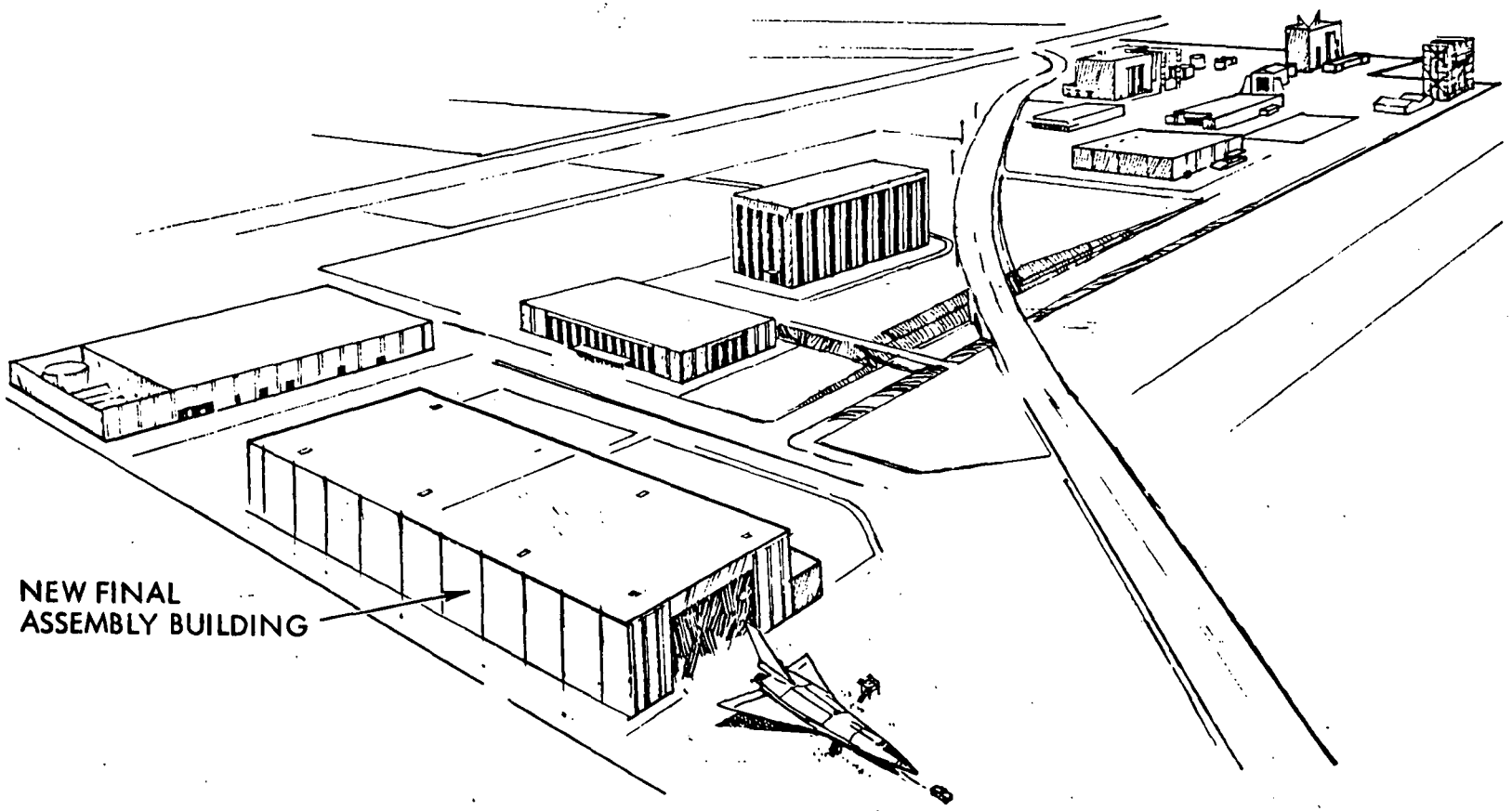

Figure 2-12. Perspective of Seal Beach Final Assembly Building

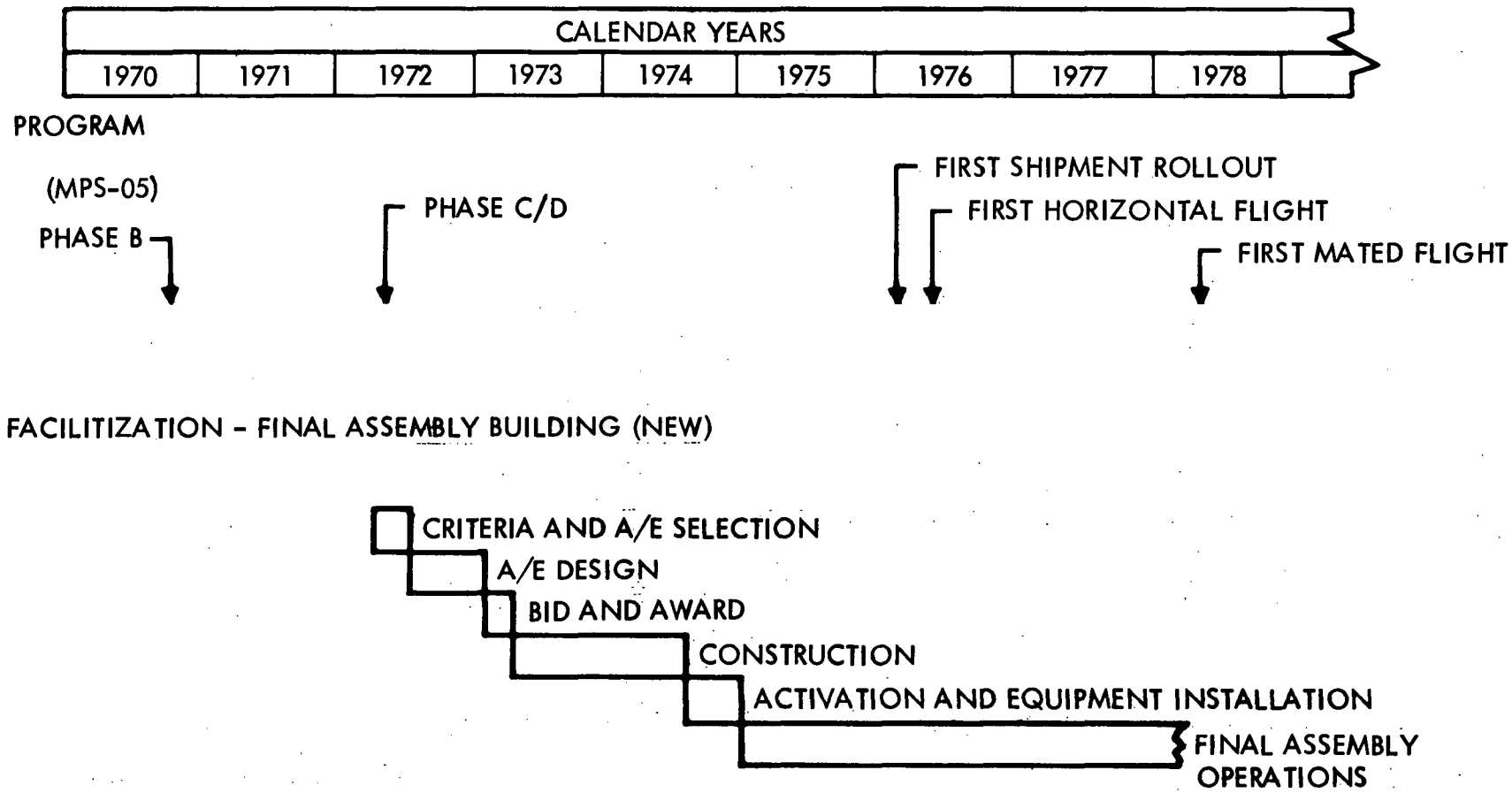

Figure 2-13. Final Assembly Building Implementation Schedule

Concurrent with the preplanning phase, local government approvals will be obtained to transport the vehicle from the final assembly building to the Naval Weapons Station dock. Required dock modifications will be coordinated with appropriate NASA and Navy personnel.

Transporation

Completed vehicles will be towed to the Navy dock (approximately one mile) and barged to Point Mugu for fly-out to the horizontal flight test site. This plan utilizes a multiwheel transporter to distribute vehicle weight within highway load limits. The transportation system is similar to that used to transport the S-II booster. The highway is eight lanes wide, providing adequate clearance for orbiter wings. A planned freeway will pass under the highway. The California Division of Highway has planned the overcrossing to accommodate the combined weight of the orbiter and transporter. At the dock, the transporter and orbiter vehicle will be rolled onto a transport barge, towed by tug to Point Mugu (Figure 2-14), rolled off the barge, towed to the flight strip for preflight testing, and then flown to the flight test site. A new dock will be required at Point Mugu, and minor modifications will be required at the Navy dock site at Seal Beach.

Support

Final assembly manufacturing operations will be supported by functions located both at Seal Beach and Downey. Support functions, such as engineering, with requirements for close liaison will be located in North American Rockwell Buildings 80 and 81 at the Seal Beach site.

Central functions such as general administration, financial administration, accounting, contracts and pricing, and developmental laboratories will provide service to the final assembly site from Downey, a 20-minute drive from Seal Beach. Communications and transportation service between Downey and Seal Beach are maintained on a regularly scheduled basis, providing continuous close liaison between Shuttle Program personnel at Seal Beach and Space Division headquarters personnel at Downey.

Computer services are provided by a large centralized computer in Building 004 at Downey. The computer is configured with direct access capability permitting query and update directly from terminal equipment at Seal Beach in major areas such as material control, production control, and engineering documentation releases.

Additional support will be provided, as required, from other aerospace divisions at North American Rockwell in the Southern California area.

Nominal rearrangement of existing office and laboratory layouts at Downey and Seal Beach to support the program will be required. Existing basic capabilities will have direct program application, permitting program continuity during the transition from Phase B to Phase C/D operations of the program.

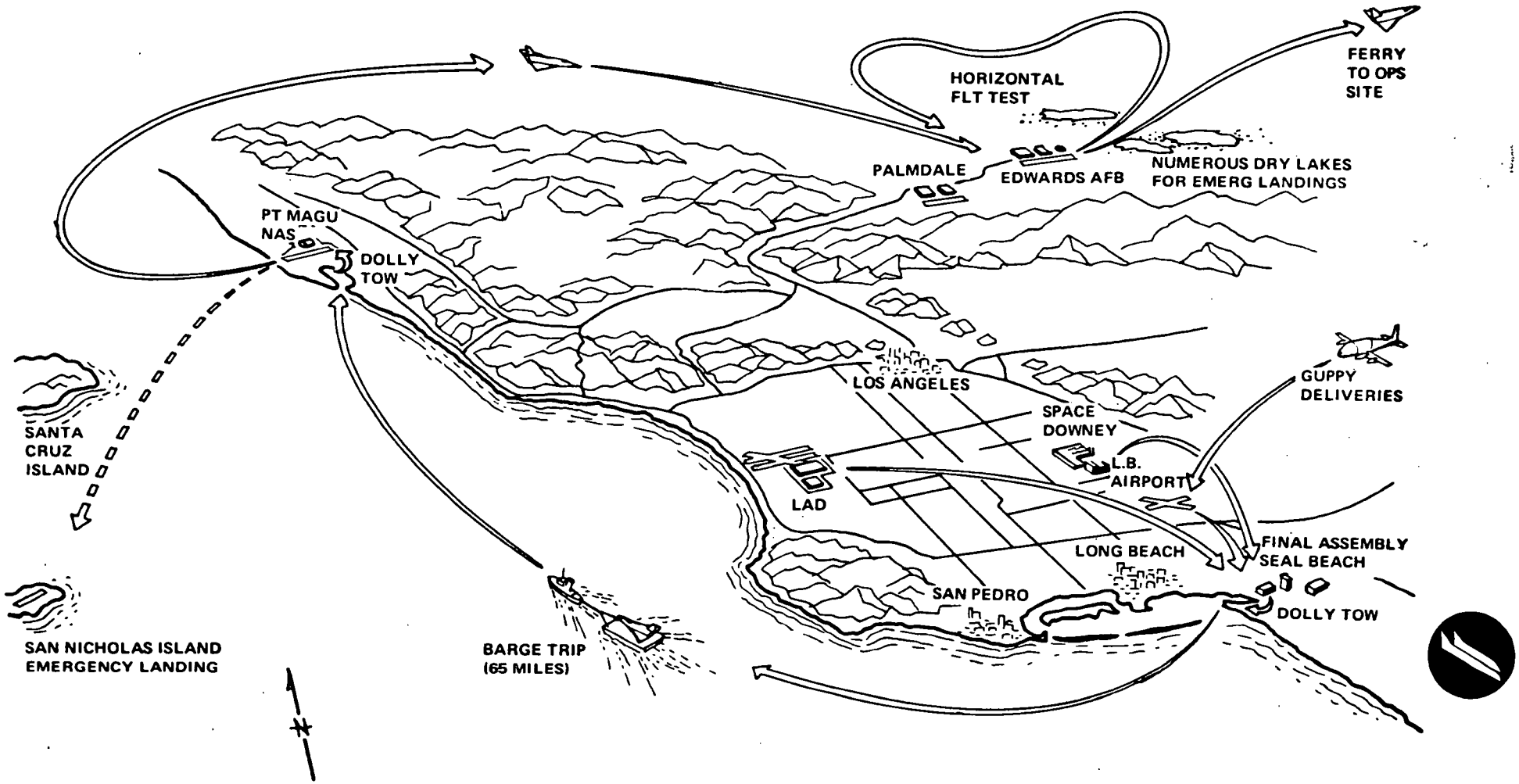

Figure 2-14. Orbiter Transportation and Ferry Route

2.2 ASSEMBLY AND DETAIL FABRICATION FACILITIES

The broad category "assembly" includes assembly of major sections as large as 79 feet by 40 feet by 23 feet as well as subassemblies and details small enough to be accommodated on bench tops.

One of the significant constraints imposed on candidate assembly sites is transportability of the major assemblies. LH_2 tanks must be accessible to water transportation systems unless built near the final assembly site. Other major assemblies also must be built either near the final assembly site, near an airport qualified for large aircraft, or at a site accessible to water transportation. Assembly of the crew module, fuselage sections, and LH_2 tank near one another would reduce integration problems as well as significantly reducing transportation problems.

Detail parts will be fabricated by existing and proven aerospace suppliers. Where feasible, parts suppliers for a specific assembly should be located in close geographical proximity to the associated assembly site to complement work schedules and to permit close liaison with supplier representatives.

Assembly of the crew module requires fabrication skills very similar to those utilized on the Apollo Program. Subsystem installation also requires specialized personnel skills similar to those used on the Apollo Program for fabricating and installing command module systems. Personnel must be certified and experienced in working with sophisticated components, with installation and checkout procedures, and with contamination control requirements. Other major sections also require aerospace-oriented assembly personnel with skill in rocket engine handling and installation, advanced welding, space insulation, cleaning, pressure testing, and handling large pressure vessels.

Major assemblies of the orbiter are the following:

1. Crew module
2. Forward fuselage
3. Main LH_2, LO_2, and OMS tanks
4. Intermediate fuselage
5. Aft Fuselage
6. Wings
7. Vertical stabilizer

Facility requirements for these assemblies and for SE fabrication are reviewed in the following subsections. Consideration is given to buildings and structures, transportation, and support shops. These requirements are summarized in Table 2-4. The machinery and equipment list in Table 2-5 is representative of the types of items required.

2.2.1 Crew Module

The crew module is a 4000-pound pressure-tight, welded compartment with machined skin and stringer panels 33 feet long by 9 feet wide. The module is divided into the pilot's section, air-lock and electronics bay, and environmental control and payload handling section (Figure 2-15).

Buildings and Structures

Fabrication of the welded compartment requires an area of approximately 26,000 square feet with a chord height of 20 feet and an additional 20,000 square feet for systems installation and checkout. The formed skins and associated components will be machined and welded, after which the crew compartment will be transferred to the pressure test facility for leak check. The test cell must provide 500 square feet of floor area and an overpressure capability of 10 pounds TNT equivalent. The assembly will be returned to the original fabrication area for structural completion, including installation of external frames, skins, and exterior supports for the thermal protection system and hot structure panels.

After cleaning and painting, the structure will be placed in an environmentally controlled area for systems installation. Installations include fixed equipment, wire harnesses, cold plates, fluid and pneumatic lines, pilot display, and control panels. Facilities required include equipment for leak checking, flushing, and sealing the fluid and pneumatic systems and a 4-ton crane. Temperature and humidity should be controlled to avoid thermal expansion and corrosion.

Transportation

The completed crew module must be shipped to the forward fuselage assembly area for fitting and functional testing. Size of the completed module permits shipment by road, water, or air. Adequate vibration protection must be provided. After fitting and functional testing, the article is shipped to the final assembly site.

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Table 2-4. Subassembly Requirements

	Crew Module	Forward Fuselage	Tanks	Intermediate Fuselage	Aft Fuselage	Wing/Stabilizer	Support Equipment
Buildings and Structures							
Assembly area							
Chord height	20 feet	35 feet	35 feet	35 feet	35 feet	30 feet	Various
Crane capacity	4 tons	8 tons	5 tons	8 tons	6 tons	6 tons	Various
Area	46,000 square feet	30,000 square feet	48,000 square feet	30,000 square feet	20,000 square feet	32,000 square feet	Various
Utilities	X	X	X	X	X	X	X
Building environment	70 to 85 F	70 to 85 F	70 to 80 F	70 to 85 F	70 to 85 F	70 to 85 F	--
Test and checkout	X	X	X	X	X	X	X
Support shops							
Machine shop	X	X	X	X	X	X	X
Electrical shop	X	X	--	X	X	X	X
Hydraulics shop	X	X	--	X	X	X	X
Tooling	X	X	X	X	X	X	X
Processing	X	X	X	X	X	X	X
Bonding	X	X	X	X	X	X	X
Tube fabrication	X	X	X	X	X	X	X
Manufacturing support offices	X	X	X	X	X	X	X
Availability	X	X	X	X	X	X	X
Transportation to final assembly							
Landing strip	OK	No	No	OK - In sections	OK - In sections	OK - In sections	OK
Water access	OK	OK	OK	OK	OK	OK	OK
Highways	OK	No	No	Local OK	Local OK	Local OK	OK
Railroads	OK	No	No	No	No	No	OK
Personnel							
Management	X	X	X	X	X	X	X
Technical	X	X	X	X	X	X	X
Skilled labor	X	X	X	X	X	X	X
Proximity Factors							
Suppliers and vendors	X	X	X	X	X	X	X
Contractor headquarters	X	X	X	X	X	X	X
Final assembly	X	X	X	X	X	X	X

X Indicates requirement
-- Indicates no requirement

Table 2-5. Typical Assembly Machinery and Equipment

Machined Details	
Jig bores	Profilers (NC/conventional)
Skin mills	Gear cutting equipment
Profiling lathes	Thread rolling equipment
Vertical lathes	Honing equipment
Engine lathes	Broaches
Milling machines (NC/conventional)	EDM machines
Multi-axis NC mills	ECM machines
Grinders	Saws and radiacs
Drill presses (NC/conventional)	Boring mills
Sheet Metal Details	
Rolls	Brakes
Punch presses	Hydro presses
Shears	Routers (NC/conventional)
NC punches	Sanding and grinding equipment
Drop hammers	Hot forming presses
Stretch forming equipment	Drills
Nibblers	Saws
Power hammers	
Processing Equipment	
Heat treating equipment	Cleaning equipment
Plating equipment	Sandblasting equipment
Chem film equipment	Chem milling
Vapor honing	Silk screen equipment
Paint equipment	Etching tanks (alkaline and acid)
Iridite tanks	Pickling and passivating tanks
Anodizing tanks	Dri-Lube equipment
Electropolishing equipment	Shot peening equipment
Drying ovens	
Bonding and Plastics	
Presses	Autoclaves
Ovens	Vacuum pumps

Table 2-5. Typical Assembly Machinery and Equipment (Cont)

Electrical Fabrication	
Wire markers	Wire strippers
Wire numbering machines	Ovens
DITMCO	
Tube Fabrication	
Benders	Flares and swaging equipment
Welders	Brazing equipment
Cleaning	
Assembly Operations	
Riveters	Electron beam weld
DC GTA (pulsed/nonpulsed)	Positioners
Resistance welders	Skate welders
X-ray equipment	Penetrant inspection equipment
Diffusion bonding equipment	
Test and Checkout	
Hydraulic flushing and pressure test	Electrical continuity
Hi-pot	Megger
GN_2 supply	GH_e supply

Support Shops

Fabrication and checkout of the crew compartment requires equipment and shop tools normally associated with aircraft assembly operations. Tooling support, electrical assembly, tubing shops, processing areas, and clean rooms are all required.

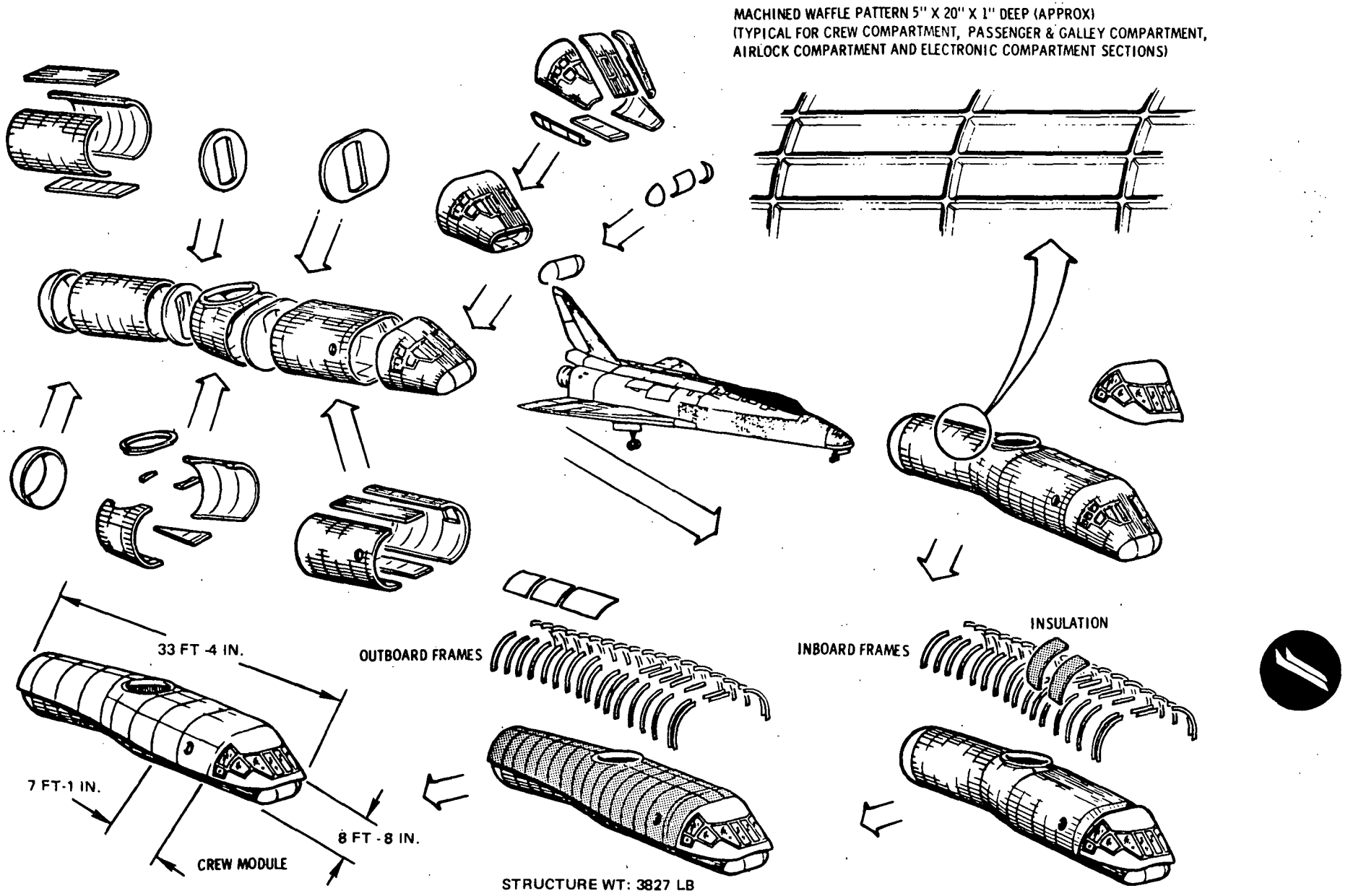


Figure 2-15. Crew Module

2.2.2 Forward Fuselage

The forward fuselage assembly consists of the LH_2 tank, forward and aft bolting structures, intravehicular access tunnel (IVA), framing, skins, thermal protection system supports, and panels. The assembly is 79 feet long by 35 feet wide by 20 feet high and weighs approximately 15,000 pounds (Figure 2-16). The LH_2 tank will be installed in the assembly tool, skirt structures will be attached, and the IVA tunnel will be installed. Longerons, frames, stringers, systems mounting provisions, REI panel supports, skins, and REI panels will be installed.

Building and Structures

The block area layout of major assembly tools establishes an area requirement of approximately 30,000 square feet. A minimum truss height of 35 feet will be adequate if breakaway tooling is utilized. The area will require bridge crane coverage of 8 tons. The capability to paint this major assembly will be required at the site. Temperature and humidity control adequate to avoid differential thermal expansion and corrosion is required. Small assemblies require an additional 15,000 square feet of low-bay area.

Transportation

Because of the size of the completed forward fuselage, long-distance transport will be limited to water transportation. Protection from the weather and salt spray will be required. Short hauls by rail or roadway may be feasible under special circumstances such as availability of adequate clearances and rights-of-way.

Support Shops

The machinery and equipment required to support assembly and checkout operations generally consists of the types of equipment listed in Table 2-5. In addition, spar mills for machining longerons will be required. Electrical and hydraulic shops, tubing shops, processing areas and tooling support will also be required.

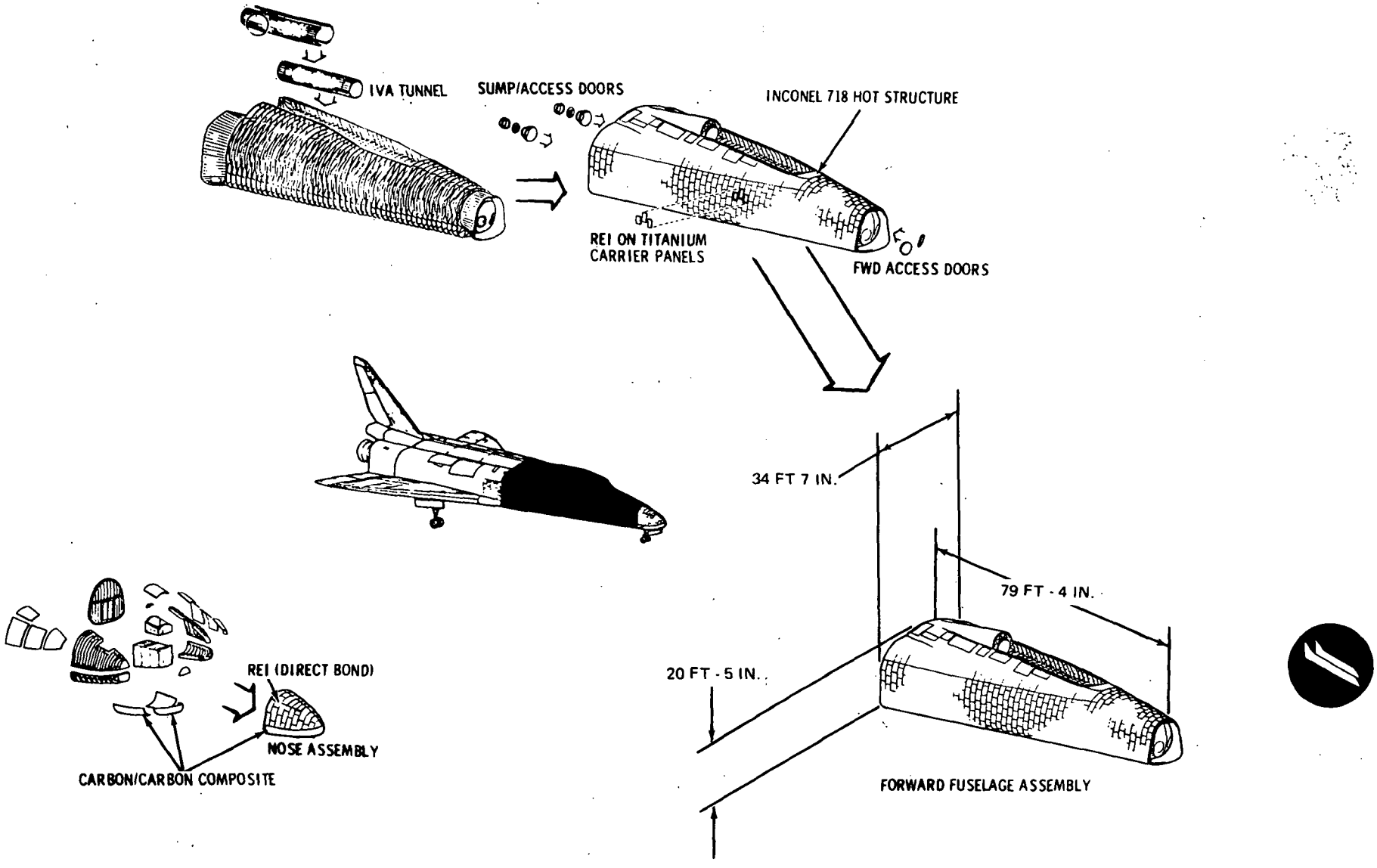


Figure 2-16. Forward Fuselage

2.2.3 LH_2, LO_2 and Orbit Maneuvering System (OMS) Tanks

The basic dimensions and weights of these tanks are as follows:

1. Main LH_2 tank: 79 ft long, 34 ft wide, 20 ft high, 6600 lb (Figure 2-17)

2. Main LO_2 tank: 47 ft long, 11 ft in diameter, 4700 lb (Figure 2-18)

3. OMS LH_2 tank: 18 ft long, 10 ft in diameter, 1500 lb (Figure 2-19)

4. OMS LO_2 tank: 9 ft sphere, 900 lb (Figure 2-20)

The main LH_2 tank assembly will be welded in six sections; two conical half shells, a center beam assembly, and three pressure bulkheads. Joints will be machined, welded, and X-rayed utilizing tool-supported tracks for mounting the equipment. Insulation will be applied to the interior tank surfaces after proof pressure testing and cleaning. Internal system components will be installed. LO_2 and OMS tanks, although smaller, will be fabricated, processed, and tested in a similar manner.

Buildings and Structures

Because it is the largest of the tanks, the LH_2 tank establishes minimum dimensions of the building. The chord height required is 40 feet (with break-away tooling). Total area of approximately 48,000 square feet and 5-ton bridge crane coverage is required. Environmental control to 75 ±5 F and 50-percent relative humidity will be required for the welding areas.

Transportation

Because of the size of the LH_2 tank, transporting the completed article will be limited to short roadway trips and water transportation. Protective covers will be required for water transport. The other tanks are not constrained by transportation difficulties.

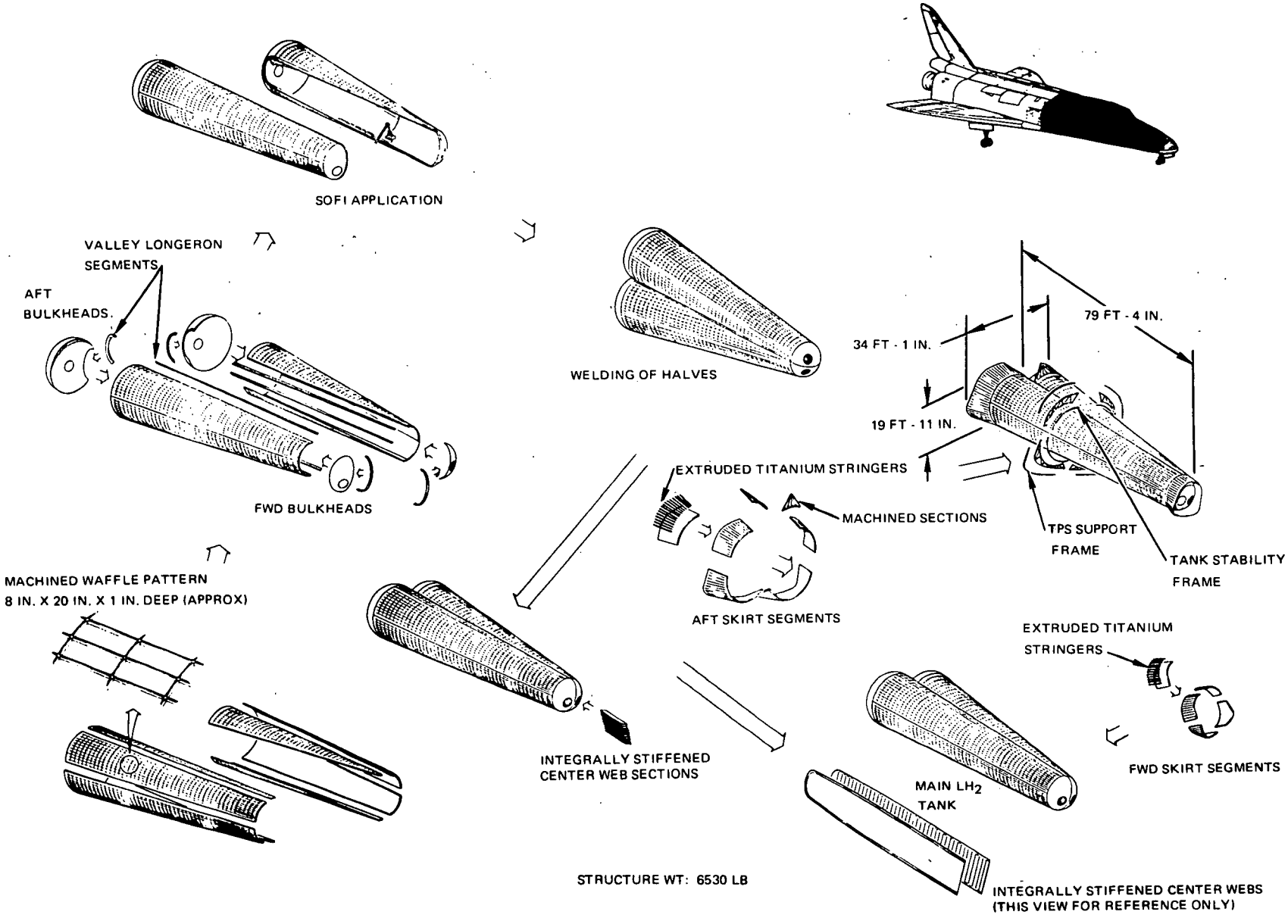


Figure 2-17. Main LH_2 Tank

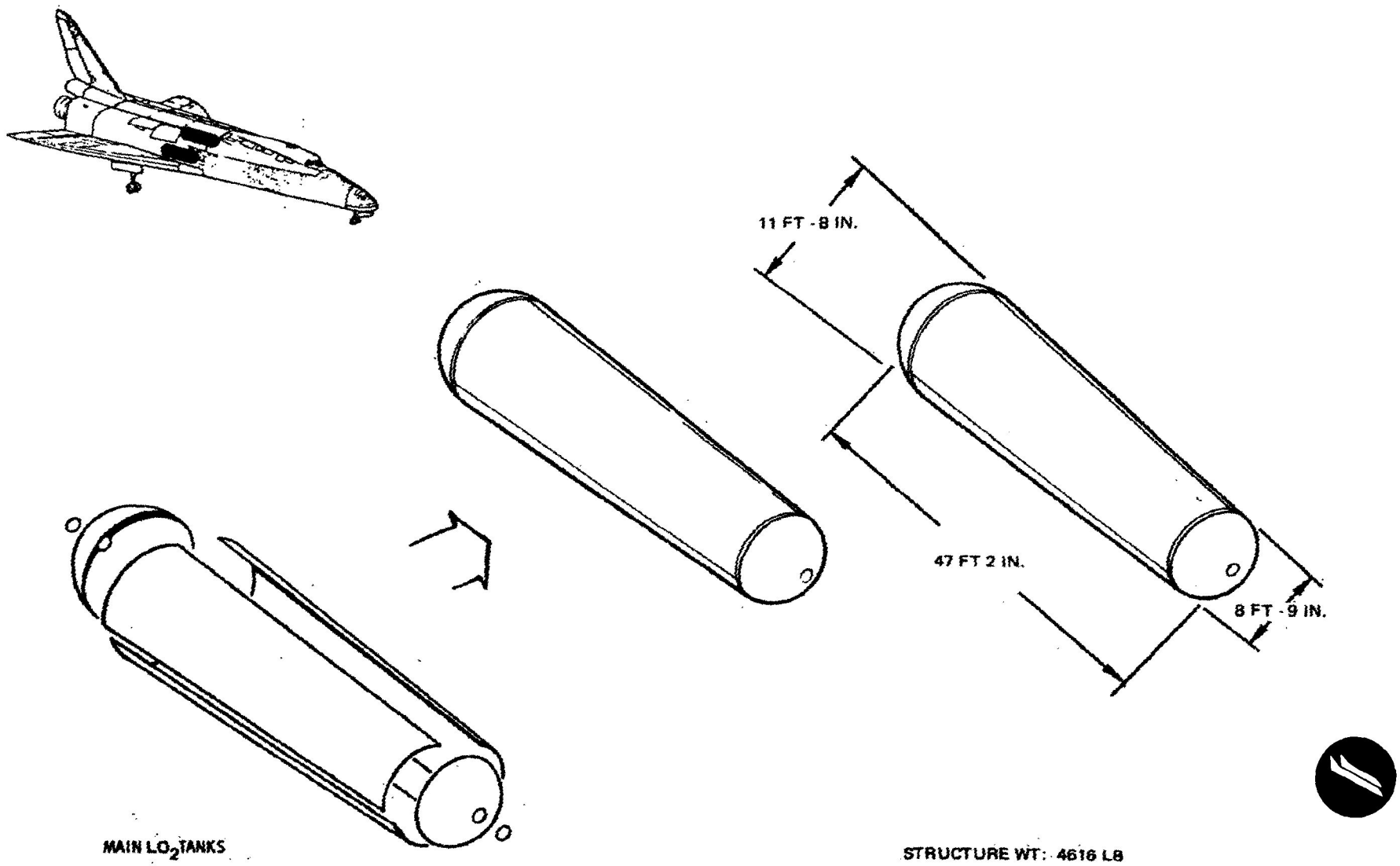
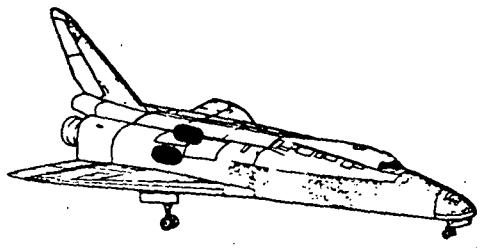
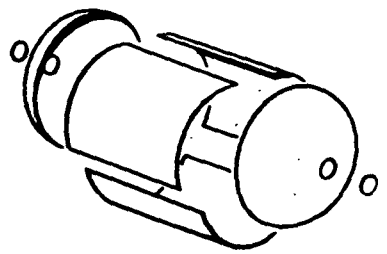
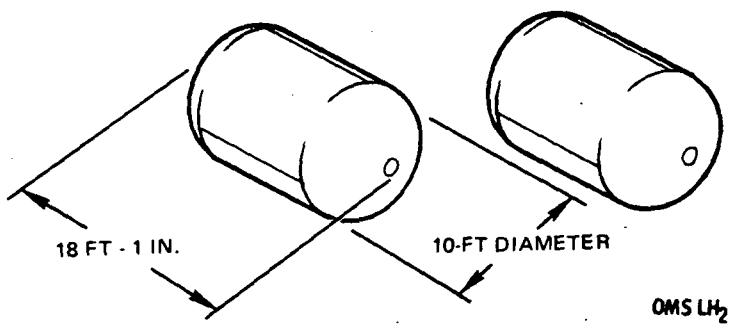


Figure 2-18. Main LO_2 Tank

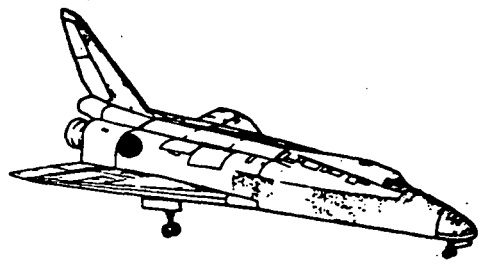






STRUCTURE WT: 1420 LB

Figure 2-19. Orbit Maneuvering System LH_2 Tank



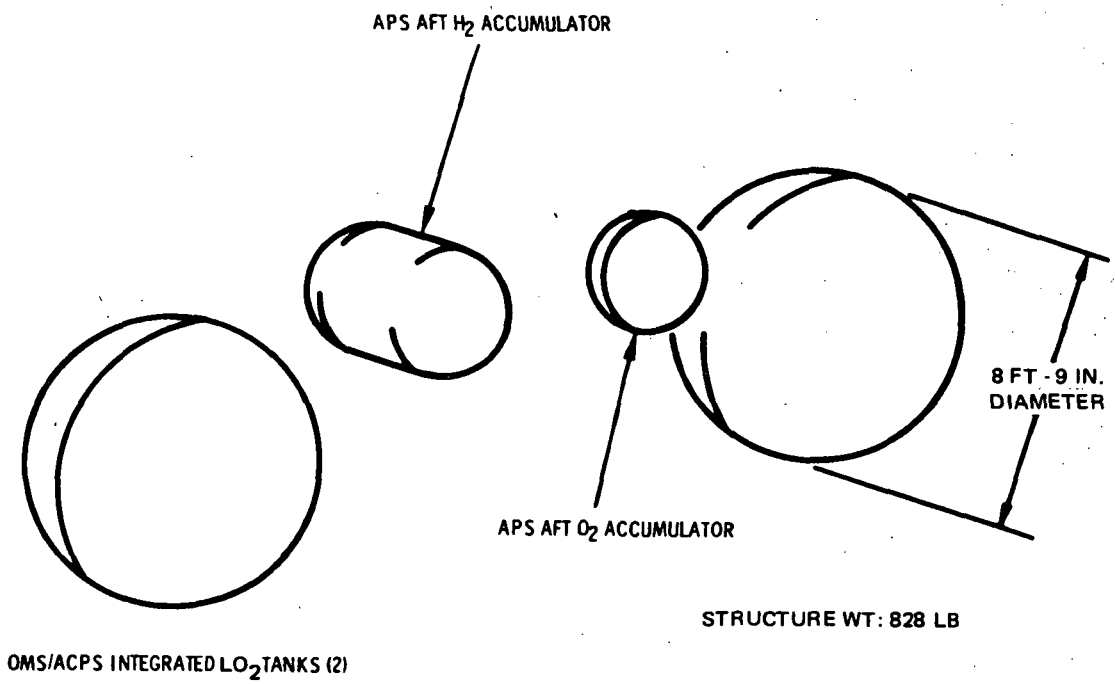


Figure 2-20. Orbit Maneuvering System LO2 Tank

Support Shops

Assembly operations for these tanks will require machinery and equipment such as that listed in Table 2-5 with the addition of bulkhead spinning equipment and hydrostatic test equipment. In addition, tooling, processing, and tubing capabilities are required to support tank and skirt fabrication.

2.2.4 Intermediate Fuselage

The intermediate fuselage is 67 feet long, 40 feet wide, and 20 feet high. It consists of frames, landing gear wells, longerons, internal machined bulkheads, webs, skin panels, tank support beams, payload deployment support structure, air-breathing engine sills, the IVA tunnel and termination frames (Figure 2-21). These structural elements manufactured chiefly from titanium and aluminum alloys will be joined by fusion welding and conventional riveting. The intermediate fuselage weighs approximately 14,000 pounds. The main LO_2 tanks and the air-breathing engines will be installed in final assembly.

Buildings and Structures

The assembly jig for the intermediate fuselage and an adjacent pickup assembly area require 12,000 square feet and a minimum truss height of 35 feet. Total assembly area is 30,000 square feet. The jig, designed for end removal, requires a crane of 8-ton capability for removal of the assembly. Temperature and humidity in the assembly area should be controlled to minimize stress buildup in dissimilar metals, to prevent corrosion, and to maintain tooling alignment. Cleanliness requirements of the assembly operation can be maintained through the use of portable clean enclosures. A minimum of 5000 square feet of other clean rooms are required for subsystems buildup and cleaning.

This section will be painted at the detail level, requiring only touch-up after final checkout; however, a paint area must be available that will accommodate the basic substructures since all interior bays must be painted prior to subsystems installation. A feasibility study has demonstrated the practicality of performing the final mate operation of the major substructures of the intermediate fuselage at the orbiter final assembly site rather than at the facility where they are built. This alternative plan reduces truss height requirements in the substructure facility to approximately 20 feet and crane capacity to 2-1/2 tons.

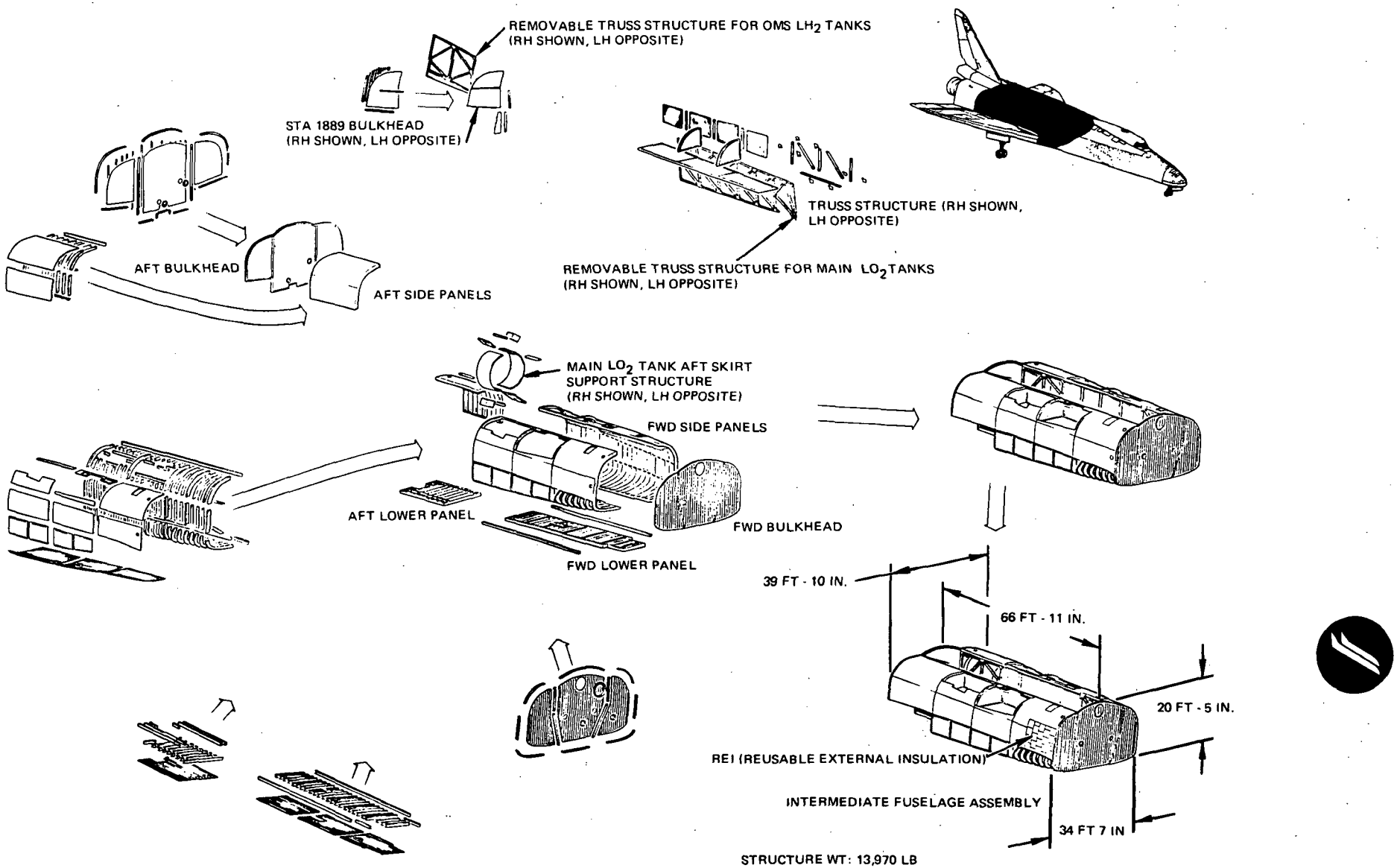


Figure 2-21. Intermediate Fuselage

Transportation

Physical size of the intermediate fuselage section necessitates water transport if shipped as a complete assembly. It can be shipped by air in sections if mating of major sections is accomplished at the orbiter final assembly facility.

Support Shops

Spar mills plus small machines and hand tools normally associated with aircraft assembly will be required in the machine shop in addition to those machines and processes listed in Table 2-5. Other shops required to support the intermediate fuselage are electrical, hydraulic, tubing, bonding, processing and tooling.

2.2.5 Aft Fuselage

The aft fuselage is 40 feet wide by 30 feet long by 20 feet high and weighs 11,000 pounds with all systems installed. This assembly is similar both in material and in fabrication technique to the intermediate fuselage. It consists of panels, thrust structure, heat shield, engine shroud, and vertical stabilizer attachment (Figure 2-22). The orbital maneuvering system (OMS) tanks and three OMS engines are installed.

Buildings and Structures

A minimum truss height of 35 feet is required to permit unloading of the final mate jig designed for end part removal. Crane capacity of 6-tons will be required. Total area requirement is approximately 20, 000 square feet.

Environmentally controlled areas are required for systems installation consisting of power generation system (PGS), attitude control propulsion systems (ACPS), propellant feedlines, and fluid systems. The final mate jig should be in an environment that is temperature and humidity controlled to the comfort level.

The assembly requires painting prior to systems installation, necessitating a facility sized to accept major substructures. Touch-up can be accomplished after removal from the mating jig.

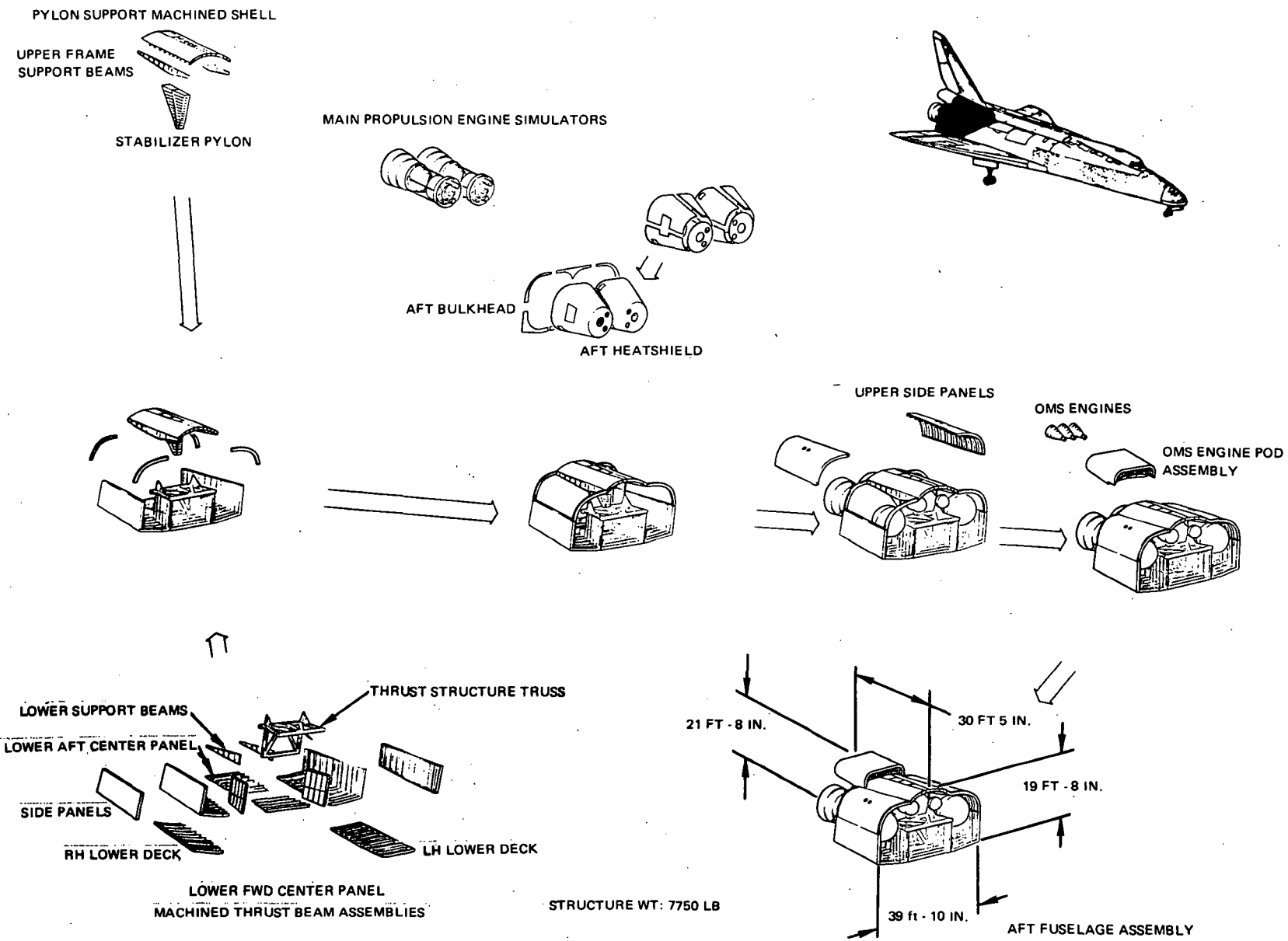


Figure 2-22. Aft Fuselage

An alternative plan to completing the entire aft fuselage at a separate site is to mate the major substructures (lower panel, upper panel, left and right side panels, thrust structure, heat shield, OMS engine shroud) and engine and systems installations at the orbiter final assembly site. This approach will reduce crane requirements to 2 tons and, with horizontal tooling, will reduce truss height to 20 feet. Since systems installations are reduced at the subassembly facility, clean room requirements are reduced.

Transportation

Transportation of the aft fuselage is limited to water conveyance because of its size. Short road hauling is practical only under specific circumstances and with special permission from local authorities. Should the alternative assembly approach be utilized, the large structural subassemblies can be shipped by air to the final assembly site.

Support Shops

The major items of machinery and equipment listed in Table 2-5 are required to fabricate and check out the aft fuselage. Small tools are assumed to be available at the facilities of any aerospace contractor capable of accomplishing this effort. Tube shops, tooling shops, electrical assembly and hydraulic assembly shops, processing, and bonding areas are also required.

2.2.6 Wings and Vertical Stabilizer

Right and left wings are each 45 feet long, 62 feet wide, and 7 feet high and weigh 10,800 pounds. The vertical stabilizer is 12 feet long, 4 feet wide, and 54 feet high and weighs less than 2000 pounds. The rudder assembly is 38 feet tall and 10 feet long at its base.

The wing assembly consists of elevons, main landing gear structure, jacking and booster attachments. The structure consists of spars, beams, truss, ribs, gear trunnion fittings, jacking and booster attachment fittings, carry-through fuselage frames, attach fittings, hinge and actuator fittings, TPS, and hot structure panels (Figure 2-23). Moving parts will be installed, fitted, checked, and removed to permit partial disassembly for air shipment to final assembly.

The vertical stabilizer and rudder assembly is made up of similar components and the fabrication techniques and shipping capability will be comparable to those used for the wing assembly (Figure 2-24).

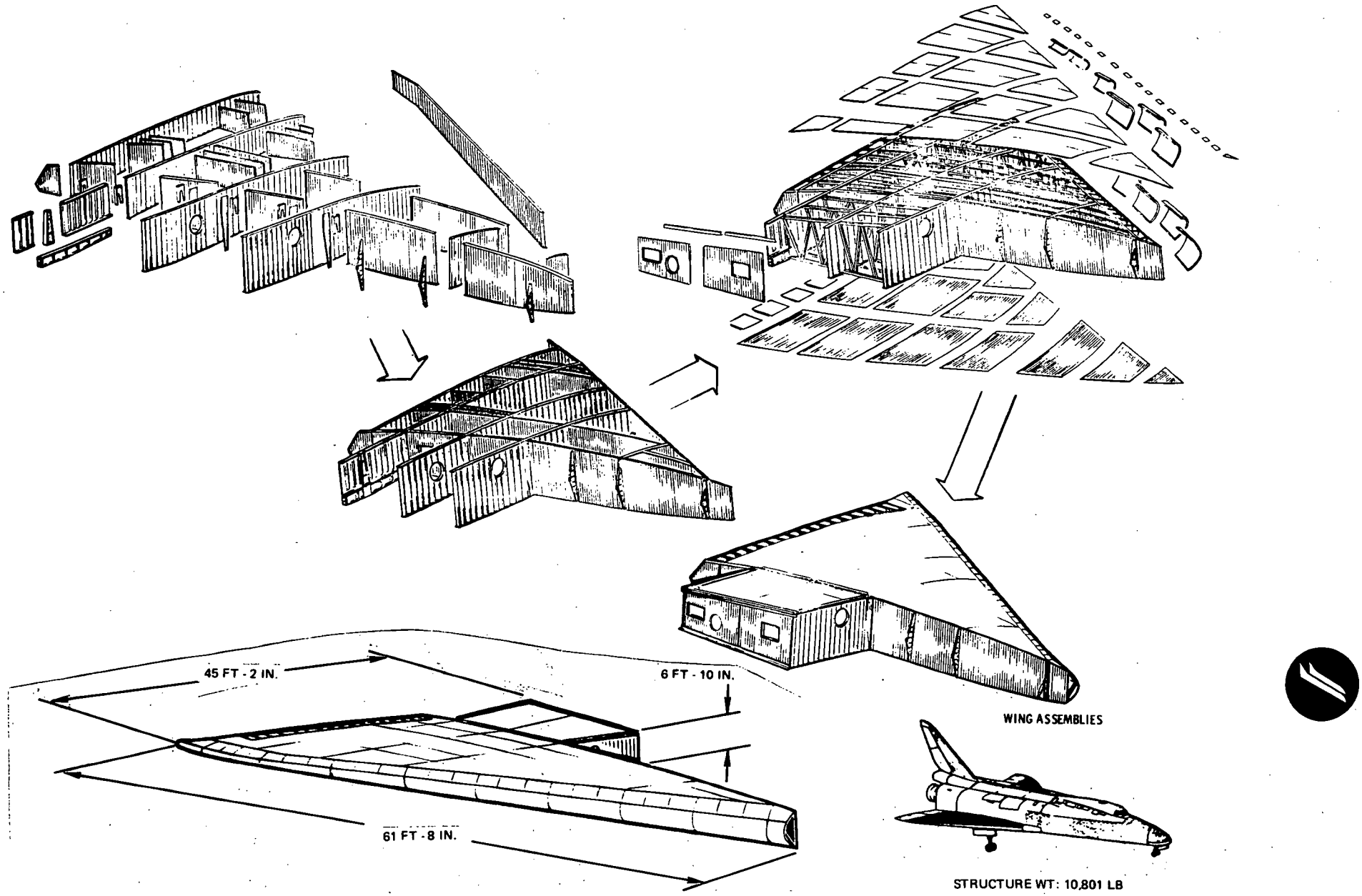


Figure 2-23. Wing Assembly

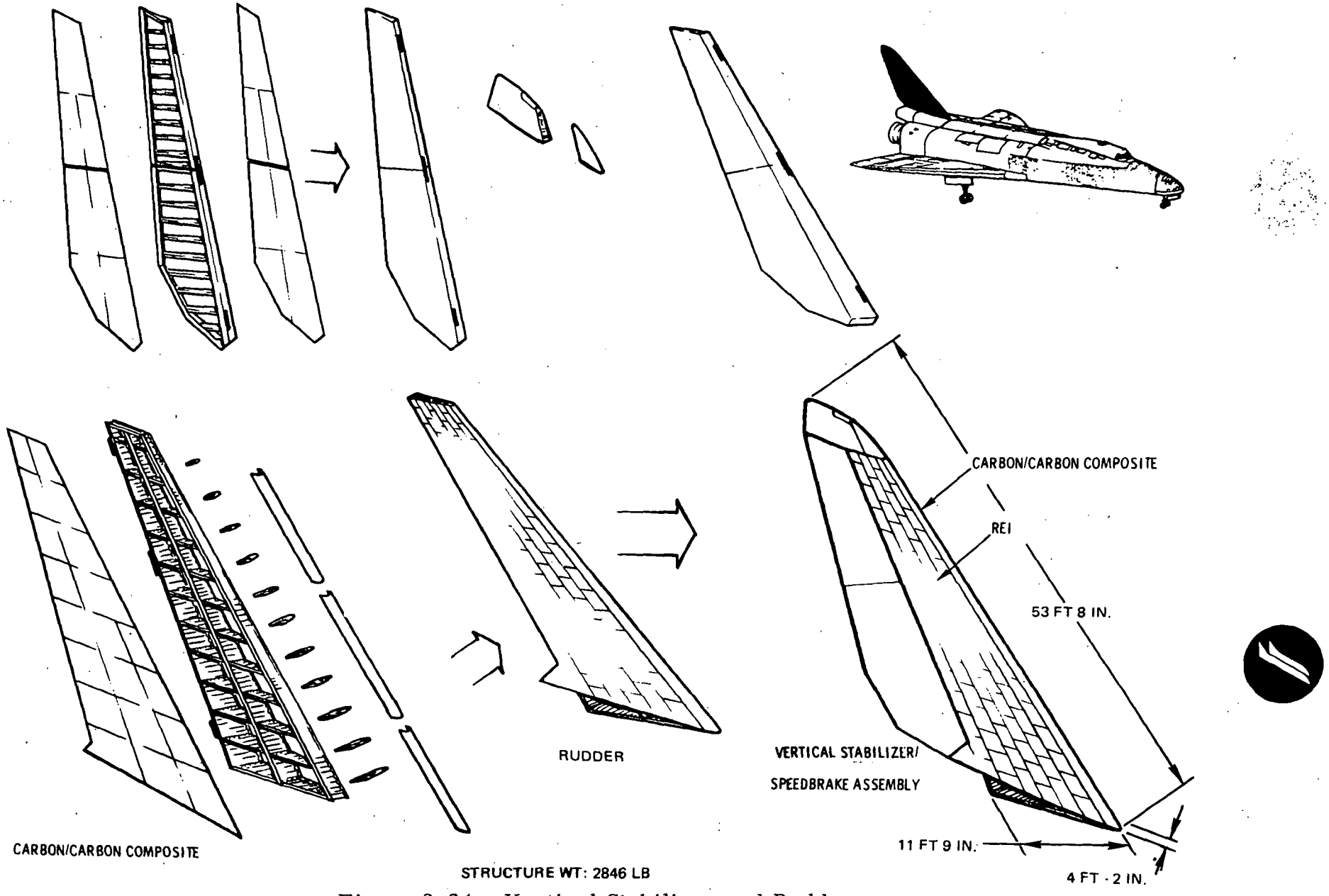


Figure 2-24. Vertical Stabilizer and Rudder

Buildings and Structures

The area required for wing and stabilizer assembly is approximately 32,000 square feet. The building requires a minimum truss height of 30 feet for horizontal assembly and bridge crane coverage of 6 tons. Environmental control is required to avoid differential expansion and corrosion.

Transportation

Wings, vertical stabilizers, and rudders are designed with breakpoints to permit partial disassembly for air shipment.

Support Shops

The operations performed on these assemblies will require machinery and equipment such as that described in Table 2-5, with the addition of drivematic riveters and spar mills. Processing facilities, welding, and bonding areas and tubing shops, and electrical and hydraulic assembly areas are also required.

2.2.7 Support Equipment

The major manufacturing effort required to produce the orbiter vehicle is directed to the vehicle itself, its assemblies, subassemblies, systems, parts, and components. It is also necessary to provide facilities for a related category of manufacturing, such as the manufacture of support equipment (SE) utilized to support checkout, flight test, launch, and service operations. This equipment consists generally of fixtures and handling equipment and checkout equipment for pneumatic, hydraulic, electrical, and other vehicle systems. It is utilized in acceptance testing and for command, monitor, and control during manufacturing, test, and operations with great emphasis on commonality of SE for all of these functions.

Buildings and Structures

Fabrication of SE workstands, adapters, covers, slings, alignment and weighing fixtures, supports, transfer units, and other associated equipment can be accomplished in conventional manufacturing facilities with adequate area, basic material handling equipment, and basic utilities. Similarly, fabrication of checkout equipment such as pneumatic consoles, hydraulic consoles, electrical consoles, panel test sets, wire harness assemblies, vacuum systems, and automated checkout equipment can be accomplished in conventional fabrication shops with some additional provisioning. A laminar flow room should be provided for pneumatic and hydraulic systems installation and checkout; small amounts of controlled environment are required to meet certain electrical and soldering specifications; and

facilities for limited pressure testing and other minor special requirements should be provided. None of these special requirments is so unique or so costly as to represent a major constraint on facilitization for support equipment manufacture.

Transportation

All support equipment assemblies and subassemblies can be transported by conventional means.

Machinery and Equipment

Equipment listed in Table 2-5 is representative of that required for GSE fabrication and assembly. Exceptions are large pieces of equipment such as skin mills, stretch forming presses, hot forming presses, electron beam welders, and autoclaves, none of which will be required.

2.2.8 Task Summary and Recommendations

For planning purposes, a preliminary make-or-buy distribution was established. Using this as a baseline, in conjunction with the facilities requirements described in the foregoing paragraphs, assembly sites for the major assemblies were selected. These are summarized in Table 2-6. Table 2-7 compares the capabilities of these selected sites with the requirements for accomplishing the assigned tasks.

The close engineering and assembly relationships between the LH_2 tank and forward fuselage and between the crew module and forward fuselage (in addition to problems associated with transporting the large LH_2 tank) provides an opportunity to effect significant cost reductions by locating the three assembly operations geographically close to each other. The similarity in structure and testing of all cryogenic tanks also makes it highly desirable to fabricate them at the LH_2 tank fabrication site. The NR and NASA facilities at Seal Beach, designed specifically for cryogenic tank fabrication and S-II systems, are ideally suited for orbiter tank manufacture.

Appropriate facilities also exist on this same site for performing buildup and assembly of the forward fuselage. The manned spacecraft fabrication facilities at Downey, 15 miles from Seal Beach, are ideally suited for fabrication and assembly of the crew module for the orbiter. This group of facilities including the Los Angeles Division detail parts fabrication support, 27 miles distant, provides an unusually complete capability concentrated in a single geographic area.

Table 2-6. Planned Site Utilization and NR Make-or-Buy Distribution

Assembly	Make-or-Buy
Tanks, main LO_2 and LH_2 Forward fuselage (LH_2 tanks) IVA tunnel Nose fuselage assembly Thrust structure Aft fuselage (OMS engine shroud)	Make (Seal Beach)
Crew module	Make (Downey)
Intermediate fuselage	Make (Tulsa - major sections) (Seal Beach - assembly)
Aft fuselage (OMS engine shroud)	Make (Columbus - major sections) (Seal Beach - assembly)
Wings Nose cone Main engine heat shield Wing fairing, leading edges, controls Cargo bay doors, liner Vertical stabilizer, rudder Landing gear, doors OMS tanks (LO_2 and LH_2) ABES nacelles	Buy

Table 2-7. Assembly Requirements and Site Comparison

	Crew Module		Forward Fuselage		Tanks		Intermediate Fuselage		Aft Fuselage		Wing and Stabilizer		Support Equipment	
	Requirements	Downey	Requirements	Seal Beach	Requirements	Seal Beach	Requirements	Tulsa	Requirements	Columbus	Requirements	Site	Requirements	Site
Buildings and Structures														
Assembly area														
Chord height	20 feet	X	35 feet	X	35 feet	X	35 feet	X	35 feet	X	30 feet	Subcont	Various	Subcont
Crane capacity	4 tons	X	8 tons	X	5 tons	X	8 tons	X	6 tons	X	6 tons	Subcont	Various	Subcont
Area	46,000 square feet	X	30,000 square feet	X	48,000 square feet	X	30,000 square feet	X	20,000 square feet	X	32,000 square feet	Subcont	TBD	Subcont
Utilities	X	X	X	X	X	X	X	X	X	X	X	Subcont	X	Subcont
Building environment	70 to 85 F	X	70 to 85 F	X	70 to 80 F	X	70 to 85 F	X	70 to 85 F	X	70 to 85 F	Subcont	--	Subcont
Test and checkout	X	X	X	New	X	X	X	X	X	New	X	Subcont	X	Subcont
Support shops														
Machine shop	X	X	X	Downey	X	Downey	X	X	X	X	X	Subcont	X	Subcont
Electrical shop	X	X	X	X	--	--	X	X	X	X	X	Subcont	X	Subcont
Hydraulics shop	X	X	X	X	--	--	X	X	X	X	X	Subcont	X	Subcont
Tooling	X	X	X	Downey	X	Downey	X	X	X	X	X	Subcont	X	Subcont
Processing	X	X	X	X	X	X	X	X	X	X	X	Subcont	X	Subcont
Bonding	X	X	X	X	X	X	X	X	X	X	X	Subcont	X	Subcont
Tube fabrication	X	X	X	X	X	X	X	X	X	X	X	Subcont	X	Subcont
Manufacturing support offices	X	Buildings 1 and 6	X	NASA and NR sites	X	NASA and NR sites	X	X	X	X	X	Subcont	X	Subcont
Availability	X	X	X	X	X	X	X	X	X	X	X	Subcont	X	Subcont
Transportation to Final Assembly														
Landing strip	OK		No		No		OK	Air shipment	OK	X	No	Subcont	OK	Subcont
Water access	OK	X	OK	X	OK	X	OK	Port of Catoosa	OK		OK	Subcont	OK	Subcont
Highways	OK	15 miles	No	Adjacent	No	Adjacent	Local OK		Local OK	Adjacent	Local OK	Subcont	OK	Subcont
Railroads	OK	X	No		No		No		No		No	Subcont	OK	Subcont
Personnel														
Management	X	Existing	X	Existing	X	Existing	X	Existing	X	Existing	X	Subcont	X	Subcont
Technical	X	Existing	X	Existing	X	Existing	X	Existing	X	Existing	X	Subcont	X	Subcont
Skilled labor	X	Existing	X	Existing	X	Existing	X	Existing	X	Existing	X	Subcont	X	Subcont
Proximity Factors														
Suppliers and vendors	X	X	X	X	X	X	X	X	X	X	X	Subcont	X	Subcont
Contractor headquarters	X	On-site	X	Local	X	Local	X	Organization established	X	Local	X	Subcont	X	Subcont
Final assembly	X	15 miles	X	Adjacent	X	Adjacent	X	Remote	X	Adjacent	X	Subcont	X	Subcont

X indicates facility meets requirements
No indicates transport not possible by means indicated

Assembly of major substructures of the intermediate fuselage is recommended for Air Force Plant No. 3 in Tulsa, Oklahoma. At this site, assembly areas of adequate truss height as well as detail fabrication facilities and clean rooms are available. Transportation of the complete assembly by water can be accomplished utilizing the newly established Port of Catoosa facilities; however, it is planned to accomplish mating of the major sections at the final assembly facility at Seal Beach. These sections will be shipped by air to nearby Long Beach Airport and trucked to Seal Beach, eliminating the requirement for barging.

Similarly, it is planned to ship the aft fuselage in major sections rather than as a complete assembly to avoid requirements for barging. The U. S. Naval Weapons Industrial Reserve Plant at Columbus, Ohio, is recommended for this manufacturing effort. The plant has all the essential capability required for the operations to be performed and is located adjacent to the Columbus airport facilitating air shipment to Seal Beach. It has 3.37 million square feet of covered area and is appropriately equipped with machinery, equipment, and personnel skills for this activity.

Completion of assembly of these sections is planned in Building S-03 at Seal Beach. The skills required for rocket engine and systems installation are available here, having been developed during the Saturn S-II Program.

2.2.9 Implementation of Seal Beach Assembly and Fabrication Facilities

The Seal Beach site is a complete facility with modern office areas, production and quality control laboratories, and other support activities. Redundant utility systems assure continuous operations. Figure 2-25 illustrates overall use of the total site.

Cryogenic Tank Fabrication, Building S-02

This building was designed and built for fabrication of the S-II bulkheads and, as such, contains temperature-controlled welding areas, bond layup and insulation application rooms, hydrostatic testing facilities, chemical processing areas, and a 36-foot-diameter autoclave. All major bays are covered by interlocking 10-ton cab-operated bridge cranes with a hook height of 41.5 feet. There are two 50-foot-high by 48-foot-wide doors, providing ample access for orbiter tanks and their subassemblies. North American Rockwell plans to perform the complete buildup of the main LH_2 and LO_2 tanks in this building. The existing hydrostatic test facility within the building will be utilized for testing bulkheads prior to installation on the LH_2 and LO_2 tank cylinders. Pneumostatic testing will be accomplished at the adjacent Naval Weapons Station as was done with S-II tanks. Tank sections

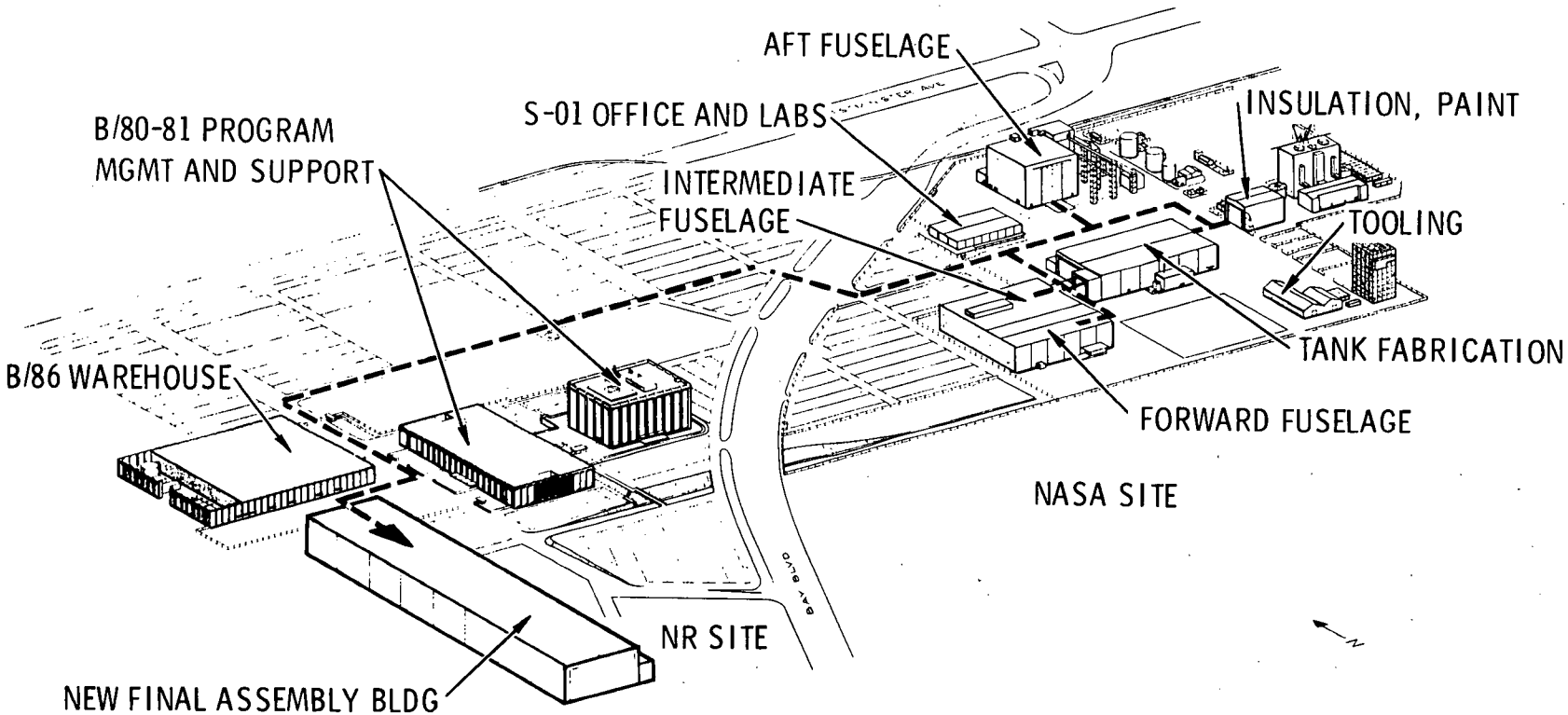


Figure 2-25. Orbiter Fabrication Facilities, Seal Beach

will be moved to the existing spray-foam room for application and finishing of internal insulation. This plan makes maximum use of the existing capabilities with minimum alteration (Figure 2-26).

Tank Cleaning and Testing Facility – Building S-03

Building S-03 (Figure 2-27) contains the tank cleaning and hydrostatic testing facility developed for S-II and is suited to these same operations for the orbiter LH_2 and LO_2 tanks. This vertical station has two 70-ton bridge cranes in which tanks up to 35 feet in diameter and 110 feet in length can be suspended and cleaned. Through an elevating boom which rises from a pit, trichlorethylene, detergent, and deionized rinse water can be sprayed into the tanks. The adjacent station, which has a crane hook height of 52 feet, is equipped to perform hydrostatic testing in tanks of less than that height. Supporting this station and the tank processing and hydrostatic test area is the site water-conditioning plant capable of processing and storing 600,000 gallons of 1.5 million OHM deionized water, distillation and storage of trichlorethylene, and heating and mixing of detergents. This plant is one of the most advanced in the industry.

Aft Fuselage Mating – Building S-03

Designed for final welding and for installation of engine systems into the S-II, this building can readily fulfill the requirements for completing assembly of the aft fuselage (Figure 2-27). The major subassemblies, including side panels, top and bottom panels, engine thrust structure, and the OMS engine shroud, built-up at the Columbus facility, will be moved by the bridge crane into the assembly jig in the adjacent bay.

ACPS systems, and OMS engines will be installed in an existing temperature- and humidity-controlled station in the same bay with the final assembly jig. This permits utilization of the existing 20-ton cab-operated bridge crane for placing of subassemblies and movement of the completed aft fuselage. This building has an existing Class-100,000 clean room for tubing, ACPS, and engine systems subassembly.

Forward and Intermediate Fuselage Assembly, Building S-14/18

When the LH_2 tank assembly is complete, it will be transported by dolly into Building S-14. This building is served throughout by a single 20-ton bridge crane with a 20-ton main hoist and 5-ton auxiliary hoists spanning 100 feet with a hook height of 43 feet 9 inches. The final mating jig for the forward fuselage and the pickup jig with its clean enclosure will be located under these cranes. Mating of the intermediate fuselage major substructures received from Tulsa and subsequent systems installation operations will also be performed in this area (Figure 2-28).

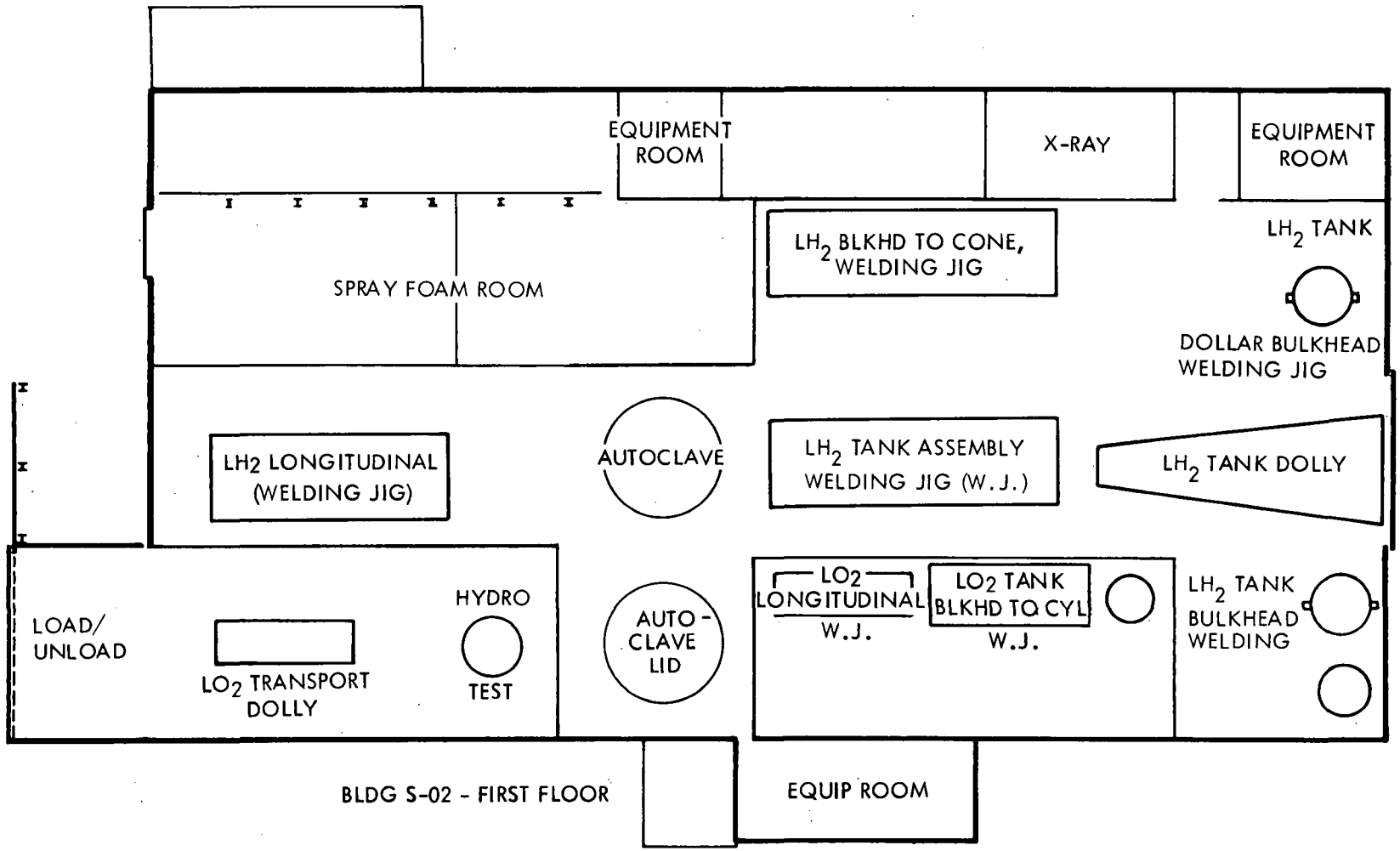


Figure 2-26. Cryogenic Tank Fabrication, Building S-02

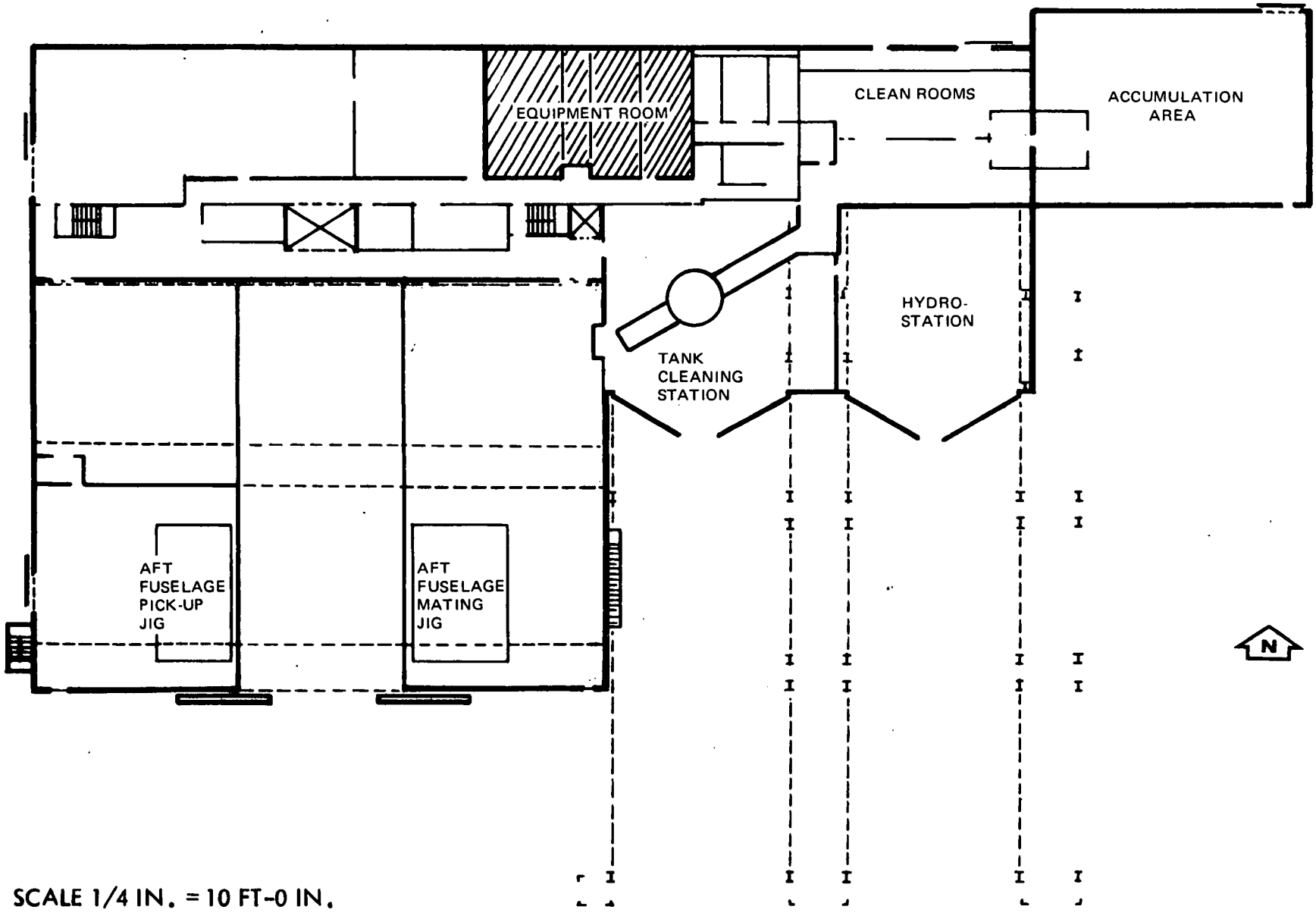


Figure 2-27. Aft Fuselage, Building S-03

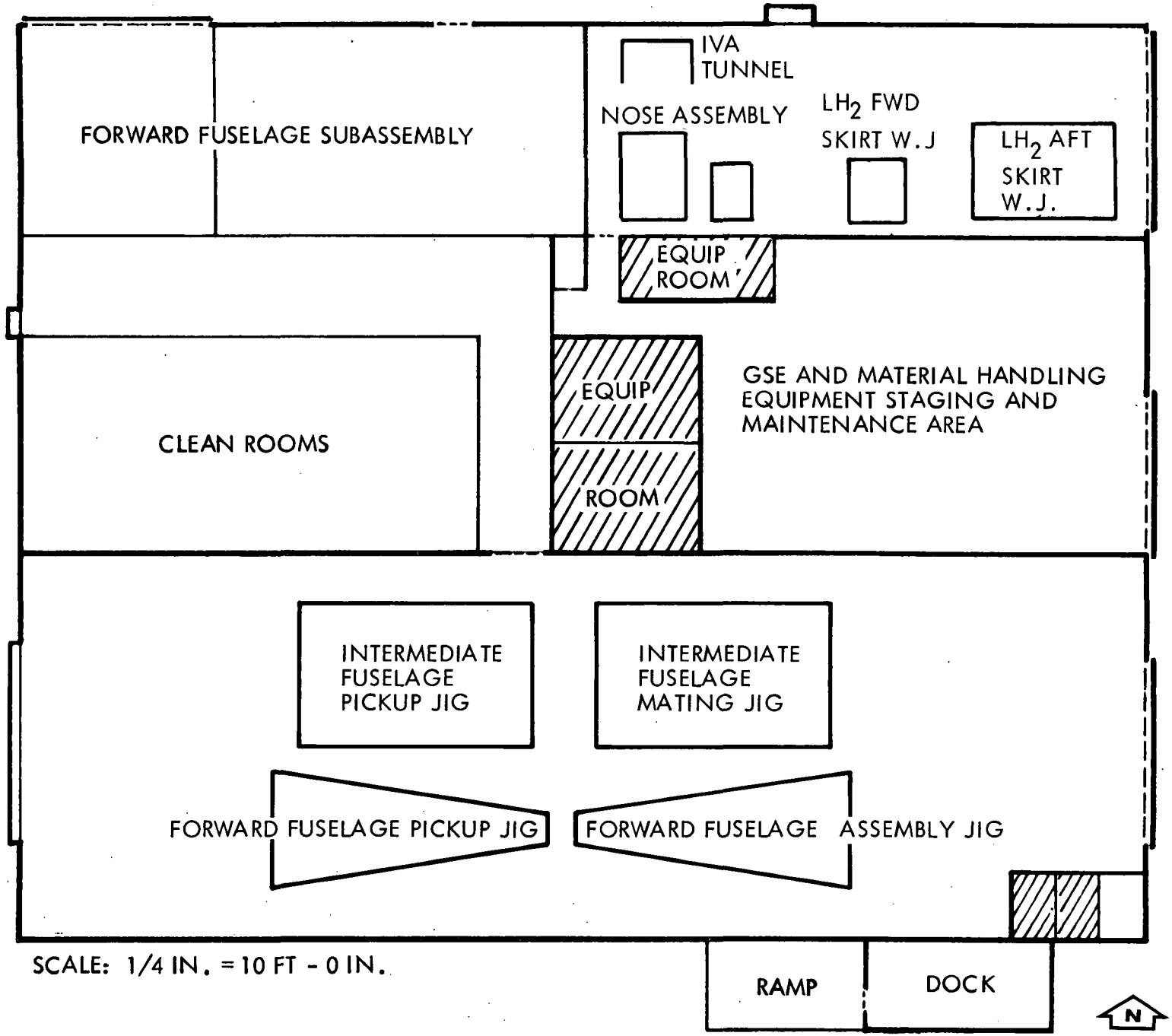


Figure 2-28. Forward and Intermediate Fuselage Assembly, Buildings S-14 and S-18

Contiguous with Building S-14 is Building S-18. This facility contains assembly areas in the north bay 50 feet wide by 300 feet long served by two 10-ton cab-operated bridge cranes. The center of the building is occupied by a three-story complex containing two clean rooms and electronic assembly and test areas. The clean rooms are Class 100,000 and Class 160,000 rooms that will be utilized for systems to be installed in the forward fuselage and nose assemblies. The north bay will house subassembly operations for the forward fuselage and also the assembly jigs for the nose section of the fuselage. An existing in-process storage area approximately 70 by 100 feet is planned for GSE and material handling equipment storage and maintenance activities. The three existing doors permit ingress and egress of the largest assemblies to be fabricated here.

Tank Insulation and Closeout and In-Tank Installations, Building S-04

This building was used to provide clean room access to the S-II tanks as well as for painting and priming operations. It is 65 feet wide by 120 feet long and contains a cab-operated bridge crane of 10-ton capacity with a hook height of 54 feet (Figure 2-29). The application of insulation, installation of in-tank subassemblies, penetrant and X-ray inspection, and final painting and closeout of the orbiter main fuel tanks will be performed in this facility.

Site Service, Building S-01

Occupancy of this existing 37,000-square-foot air-conditioned building comprises manufacturing and quality control office areas, and process control laboratories. Of primary interest are the chemical and metallurgical capabilities of the laboratories that were established to support fabrication of the S-II. These laboratories are completely applicable to the orbiter activities planned at the Seal Beach NASA site.

Tool Maintenance, Building S-05

This 17,500 square-foot building is utilized for tool fabrication rework, and verification and for maintenance support of the entire site. It is equipped with two 2-ton and one 10-ton bridge cranes.

Transportation

The proximity of the facilities described in Table 2-7 to the planned contractor-funded final assembly facility at Seal Beach simplifies the movement of major assemblies (forward fuselage, intermediate fuselage,

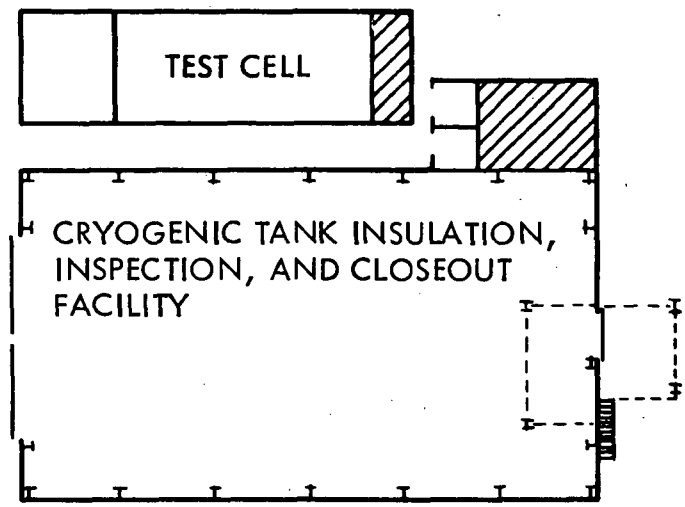


Figure 2-29. Tank Insulation and Closeout, Building S-04

aft fuselage, and main LO_2 tanks), Figure 2-25. Individual dollies will be provided to accomplish this transport. The transport of these assemblies will be accomplished by utilizing the dollies used in final assembly operations with roadable wheels added. Wide-load permits and police escorts will be provided by the City of Seal Beach as in the transport of the Saturn S-II.

2.2.10 Implementation of Downey Fabrication and Assembly Facilities

The NASA-owned Downey complex, headquarters of the NR Space Division, will perform most of the machining, sheet metal fabrication, tooling, and wire harness fabrication to support the Seal Beach assembly operation. In view of the unique capabilities developed in Downey under the Apollo Program for assembly of completed manned spacecraft, NR plans to fabricate and assemble the critical orbiter crew module here.

Crew Module Systems Installation and Checkout, Building 290

Building 290, built for Apollo spacecraft final assembly and test (Figure 2-30), is a highly compatible with the requirements for the systems installation, inspection, and checkout of the crew module.

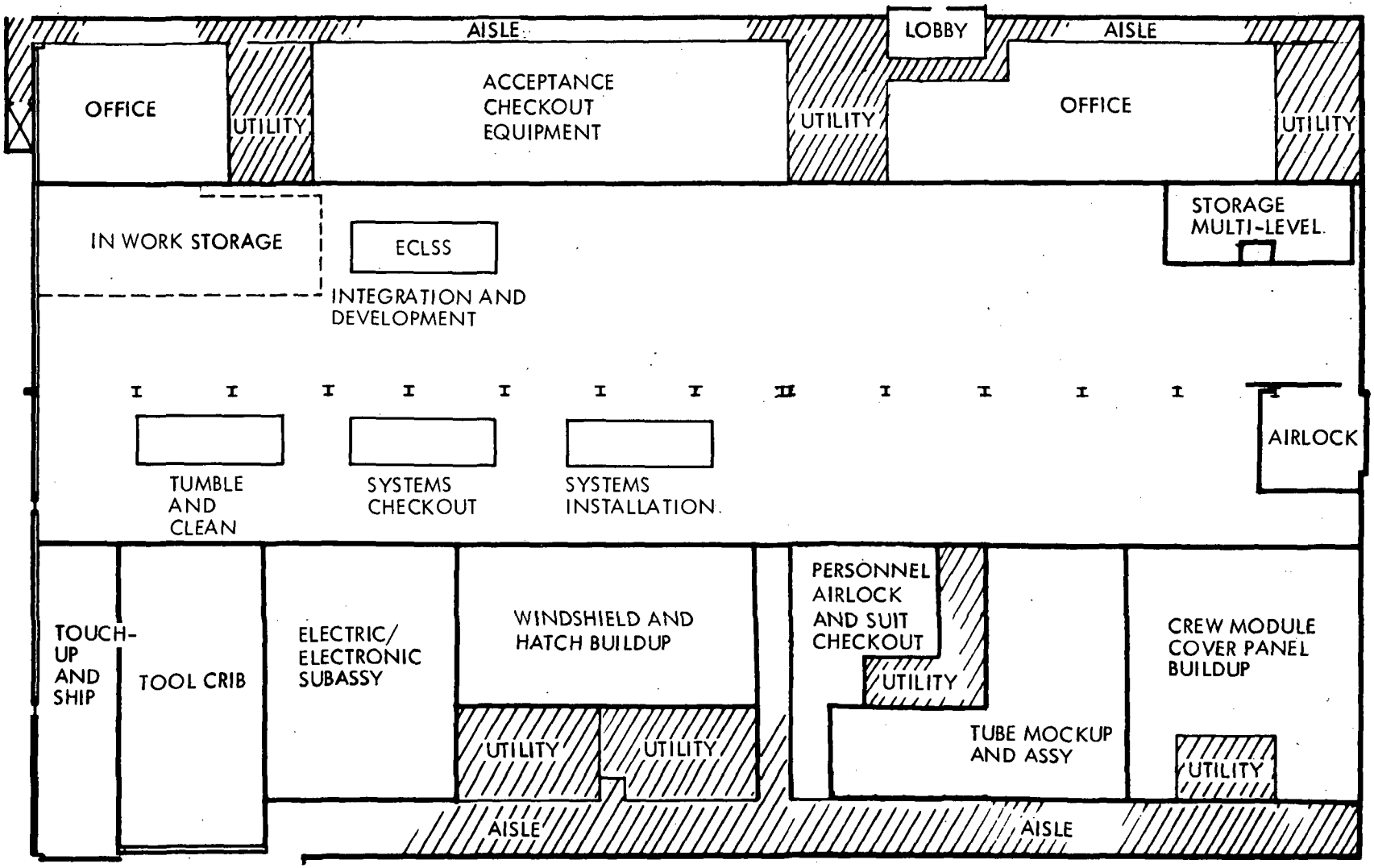
The total area of 46,000 square feet of high bay is capable of 300,000 class cleanliness. Utility trenches provide power and compressed air to all using areas. Crane coverage is complete with 10-ton capacity on the west side and 15-ton capacity on the east. Lighting is at 100 foot-candle maintained throughout the high-bay area.

Storage for checkout gear, protective covers, handling equipment, and related items can be provided by the existing storage stand in the northwest corner of the Building 290 high bay. This three-level stand has floor dimensions of 24 by 60 feet and a height of 30 feet.

The adjacent low-bay area provides 25,000 square feet for support operations such as window and hatch buildup, instrumentation and electrical system buildup, tubing fabrication, and tool cribs. A Class 340,000 clean room is also located here, providing the capability for clean subassembly effort.

Main Building 001

The primary building on the Downey site, Building 001, is planned for use in tooling fabrication, detail mechining, sheet metal detail parts fabrication, and wire harness fabrication (Figure 2-31). Welding of the crew module structure will also be performed in this building. Tooling effort for



Bldg. 290 - First Floor

Figure 2-30. Crew Module Fabrication and Checkout

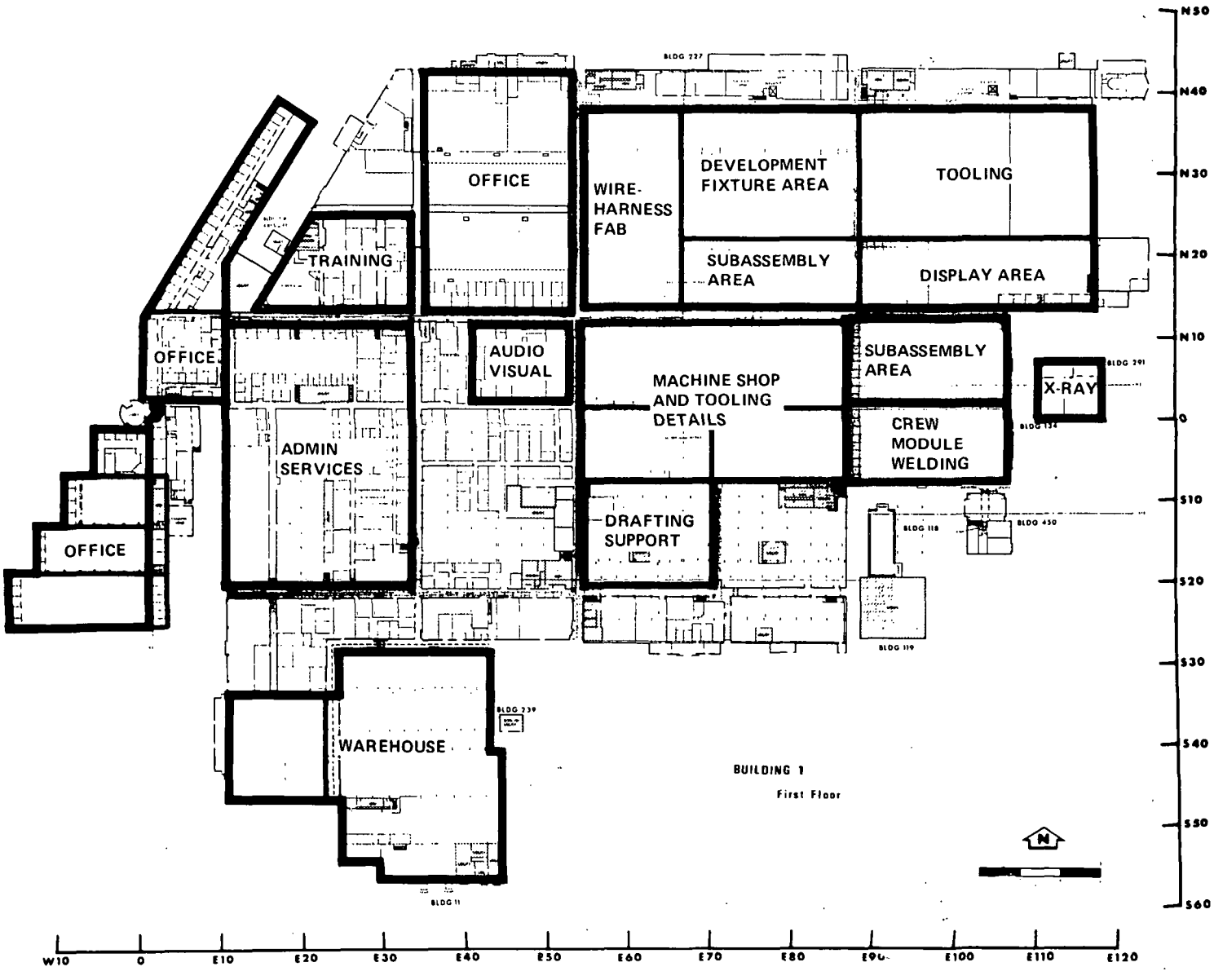


Figure 2-31. Production Facility

the orbiter assembly operations to be performed in Southern California can readily be accomplished in the extensive shops located here. Major assembly tool structures will be fabricated in the areas in which they are to be installed, but all tooling management, tooling engineering, and details will be accommodated in Building 001.

This building contains over 64,000 square feet of area dedicated to the fabrication of detail parts. Extensive capacity for tape-controlled and conventional machining exists for support of fabrication and tooling efforts.

The consolidated wire harness fabrication facility has been recently completed. Containing 32,000 square feet of area, this clean room is completely temperature-controlled. It is one of the best equipped in the area and will support orbiter requirements.

Pressure Test Cell, Building 260

This test cell is a completely instrumented underground silo (Figure 2-32) providing maximum safety during test. It is used presently to pressure-test the Apollo service module. With minor modifications the cell can be used to pressure-test the crew module. Modifications include increasing the height of the cell by 10 feet.

Other Buildings

The complete production capability of the Downey site will be utilized on the program. This includes modern bonding and processing facilities, heat treatment, painting, tube cleaning and forming, plastics layup, cold plate bonding, warehousing, and indirect production support facilities.

2.2.11 Implementation of Tulsa Fabrication and Assembly Facilities

The NR Tulsa Facility consists of three basic sites; Air Force Plant 3, at the Tulsa International Airport, the leased Mingo facilities at the Airport, and the American Airlines Maintenance and repair facilities. (Figure 2-33).

The main building at Air Force Plant 3, Building 1, will be used for intermediate fuselage details and subassembly. The Tulsa Plant is well suited to the fabrication of this structure, with excellent machining, sheet metal and bonded structure capability. Low-cost, high-quality production is shown by the success achieved on the subcontracted structures for the Boeing 747.

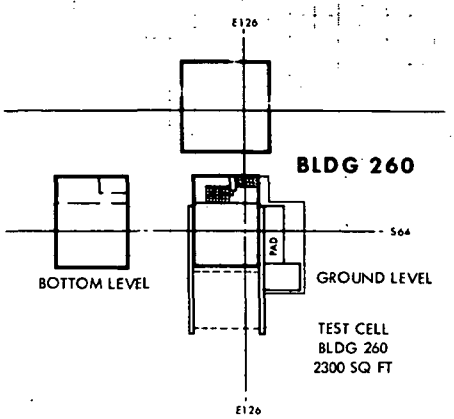


Figure 2-32. Pressure-Test Cell

Assembly Building

The assembly building has a main bay 200 feet wide, served by cab-operated bridge crane systems of 15-, 5-, and 2-1/2 ton capacity. Air conditioning provides a stable environment for the large tooling required for the orbiter intermediate fuselage (Figure 2-34). Existing extensive shops in this building minimize requirements for obtaining detail fabrication from outside sources. Chemical processing and painting facilities in support of these detail fabrication shops are immediately adjacent. Bonded structure capacity includes autoclaves of 20-, 14-, and 9-foot diameters, as well as smaller autoclaves and heated platen presses.

Transportation

The experience gained through shipment of the Saturn/Apollo spacecraft LEM adapter and the Apollo service module via Guppy aircraft from this plant is applicable to intermediate fuselage transportation.

The NR-leased hangar at Long Beach Airport has also been used as a shipping and receiving terminal for Apollo hardware including the service module shipped from Tulsa. The surface route from the Long Beach airport to the Seal Beach Facility was utilized in the S-II Program. No obstacles exist on this route to hinder the movement of orbiter subassemblies. This demonstrated capability for shipment of large assemblies from Tulsa to southern California via aircraft illustrates the practicality of this plan.

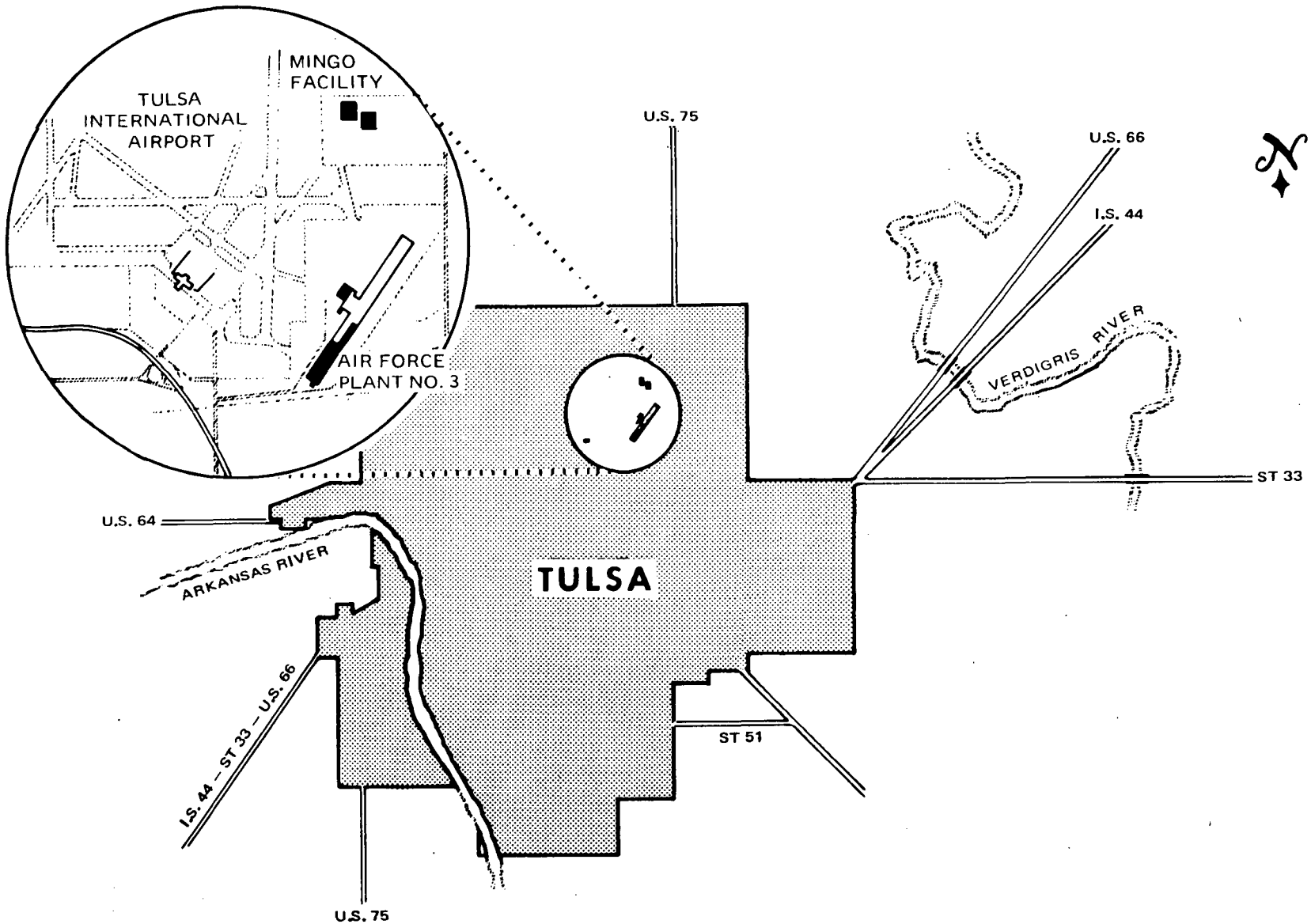
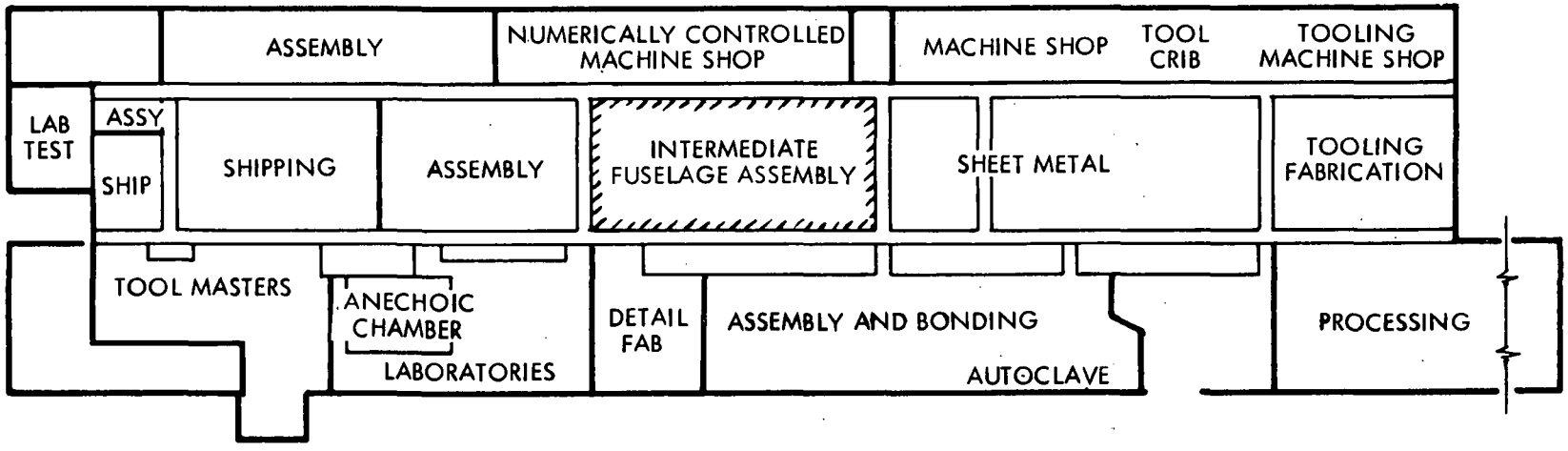


Figure 2-33. Tulsa Division Facilities



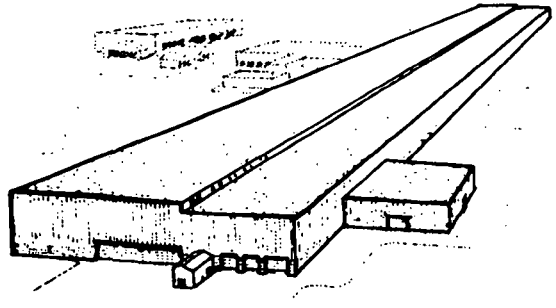


Figure 2-34. Tulsa Assembly Building 1, Air Force Plant 3

2.2.12 Implementation of Columbus Fabrication and Assembly Facilities

The Columbus Division of NR occupies the Naval Weapons Industrial Reserve Plant at Columbus, Ohio. This plant is situated adjacent to the airport on 521 acres of ground and has 3.370 million square feet of covered area. The facilities there are readily adaptable to the fabrication of the substructures of the orbiter aft fuselage. Demonstrated aircraft fabrication skills gained on such programs as RA-5C, T-2D, and OV-10A aircraft are available.

Assembly Building

The main assembly building at Columbus (Figure 2-35) is temperature controlled with more than adequate crane capacity, bay width, and height. There are over 7500 pieces of major machinery and equipment that are continually modernized to satisfy new production requirements. Capabilities include metal cutting, metal forming, metal joining, processing, finishing, plastics and honeycomb fabrication, and assembly.

Transportation

The location of the Columbus Division on the airport permits transport of the aft fuselage substructures by air. As stated in Section 2.2.11, the practicality of this mode has been demonstrated on the Apollo and Saturn S-VI programs.

2.2.13 Implementation of Los Angeles Fabrication and Assembly Facilities

Of significant importance to orbiter fabrication is the capability for machining at the NR Los Angeles Division. NR, recognizing the trend to hard metals and increased requirements for profiling capacity in aircraft design and construction, implemented a $27 million modernization of the machining center at the Los Angeles Division, which is now nearing completion (Table 2-8 and Figures 2-36 through 2-40). Eighty-five major machines with a total of 159 spindles have been installed in approximately 150, 000 square feet of area. Sixty percent of the skin mills, spar mills, and profilers in the inventory are multispindle, multiaxis, numerically-controlled machines. An example is the 12- by 375-foot skin mill which has six gantries and 24 spindles. The center also has some smaller tracer and manually controlled machine tools, and a full complement of supporting equipment. An automatic drafting machine is used to proof tapes for numerically controlled machines.

BUILDING 3
ADMINISTRATIVE AND GENERAL OFFICES
MACHINE SHOP
MAJOR AND FINAL ASSEMBLY
PLASTICS
PROCESSING AND HEAT TREATING
SHEET METAL FORMING
TOOLING
WELDING AND BRAZING
BUILDING 4
MATERIAL DIVISION
RECEIVING
SHIPPING
BUILDING 5
FINAL PAINT AND STRIPPING
BUILDING 6
ELECTRICAL
ELECTRONICS
ENGINEERING DIVISION
EXPERIMENTAL
HEAVY MACHINING
PRODUCTION DEVELOPMENT LAB
MAJOR AND FINAL ASSEMBLY
BUILDING 7
ACOUSTICAL LAB
ENGINEERING LABS
EXPERIMENTAL
PRODUCTION FLIGHT TEST
BUILDING 7A
ENGINEERING FLIGHT TEST
STRUCTURES LAB
BUILDING 8
POWER HOUSE
BUILDING 9
MAINTENANCE
BUILDING 21
MAINTENANCE
BUILDING 124
FUEL TEST LAB
BUILDING 125
TOOL STORAGE AND SALVAGE SALES
BUILDING 210
SUBSONIC WIND TUNNEL
BUILDING 214
ENGINEERING ENGINE TEST CELL
BUILDING 245
ANTENNA AND RADOME LAB
BUILDING 252
PRODUCTION ENGINE TEST CELL
BUILDING 259
BOMBING NAVIGATION FACILITIES
BUILDING 271
CRYOGENICS LAB
THERMO LAB

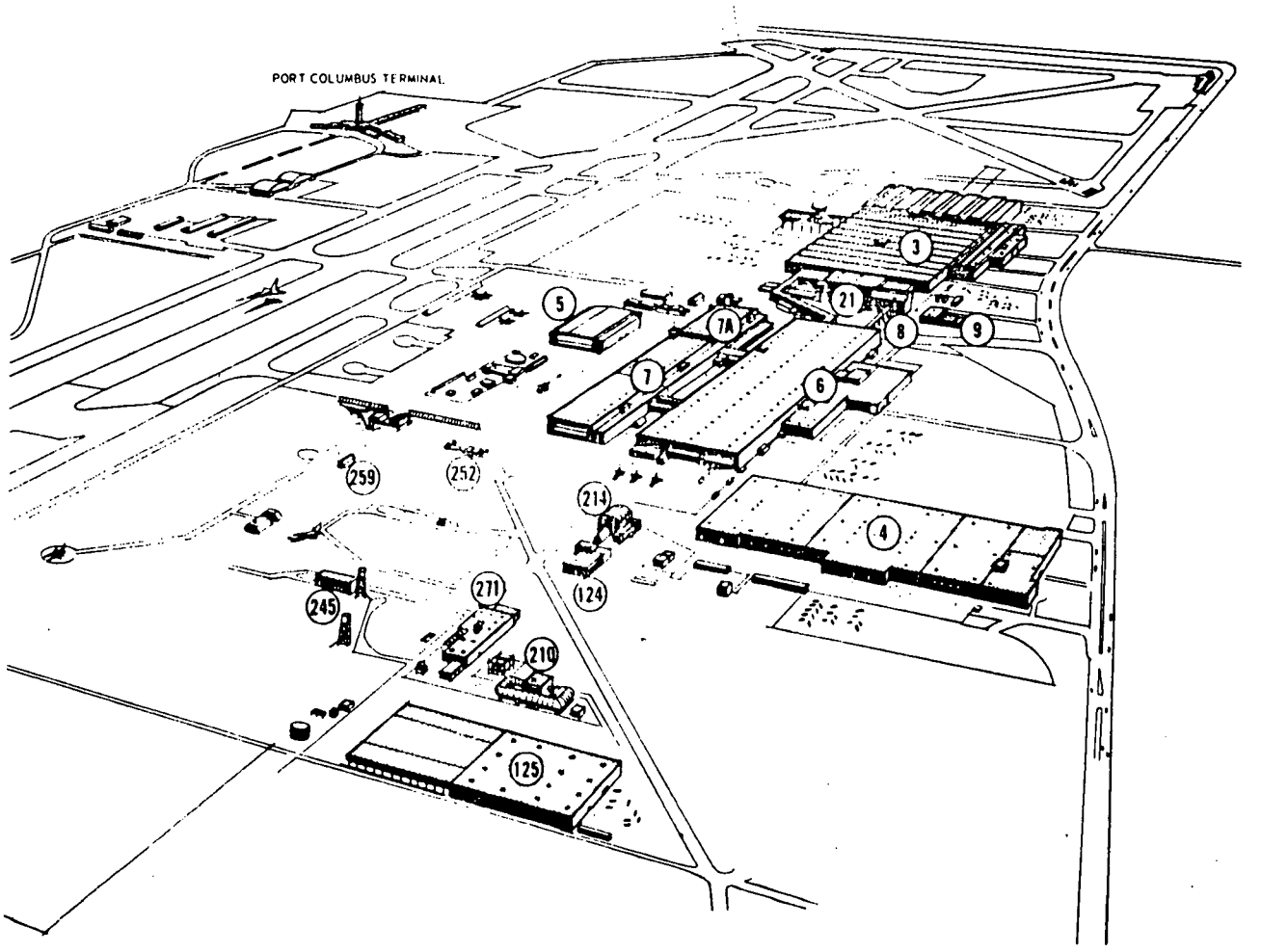


Figure 2-35. Columbus Division Plant Facilities

An extremely versatile machine installed in the Center is the Froriep numerically-controlled vertical turning, boring, and milling machine. This five-axis machine can swing parts up to 43 feet in diameter and has a table load capacity of 75 tons. The table is driven by a 100-horsepower motor; the milling head is 25 horsepower.

This outstanding machining center will be used for milling titanium and aluminum structural members, castings, and forgings for the orbiter.

A schedule for implementation of detail fabrication and assembly is shown in Figure 2-41.

2.2.14 Summary of Fabrication and Assembly Requirements

Major facilities required for detail fabrication and assembly are listed in Table 2-9.

Table 2-8. Structural Machining Facility Capability—Los Angeles Division

Machine Type	Maximum Bed Size (feet)	On Hand		Being Installed		Total	
		Quantity	Spindles	Quantity	Spindles	Quantity	Spindles
Profilers	8 x 50	20	41	11	31	31	72
Skin mills	12 x 375	8	17	5	18	13	35
Spar mills	3 x 210	5	12	2	6	7	18
Detail mills and drills	2 x 9	23	23	0	0	23	23
Bed mills	2.5 x 14	7	7	0	0	7	7
Electrochemical machining	8 x 4 x 5	3	3	0	0	3	3
Vertical turning boring machine (Froriep)	43 (diameter)	0	0	1	1	1	1
Total		66	103	19	56	85	159

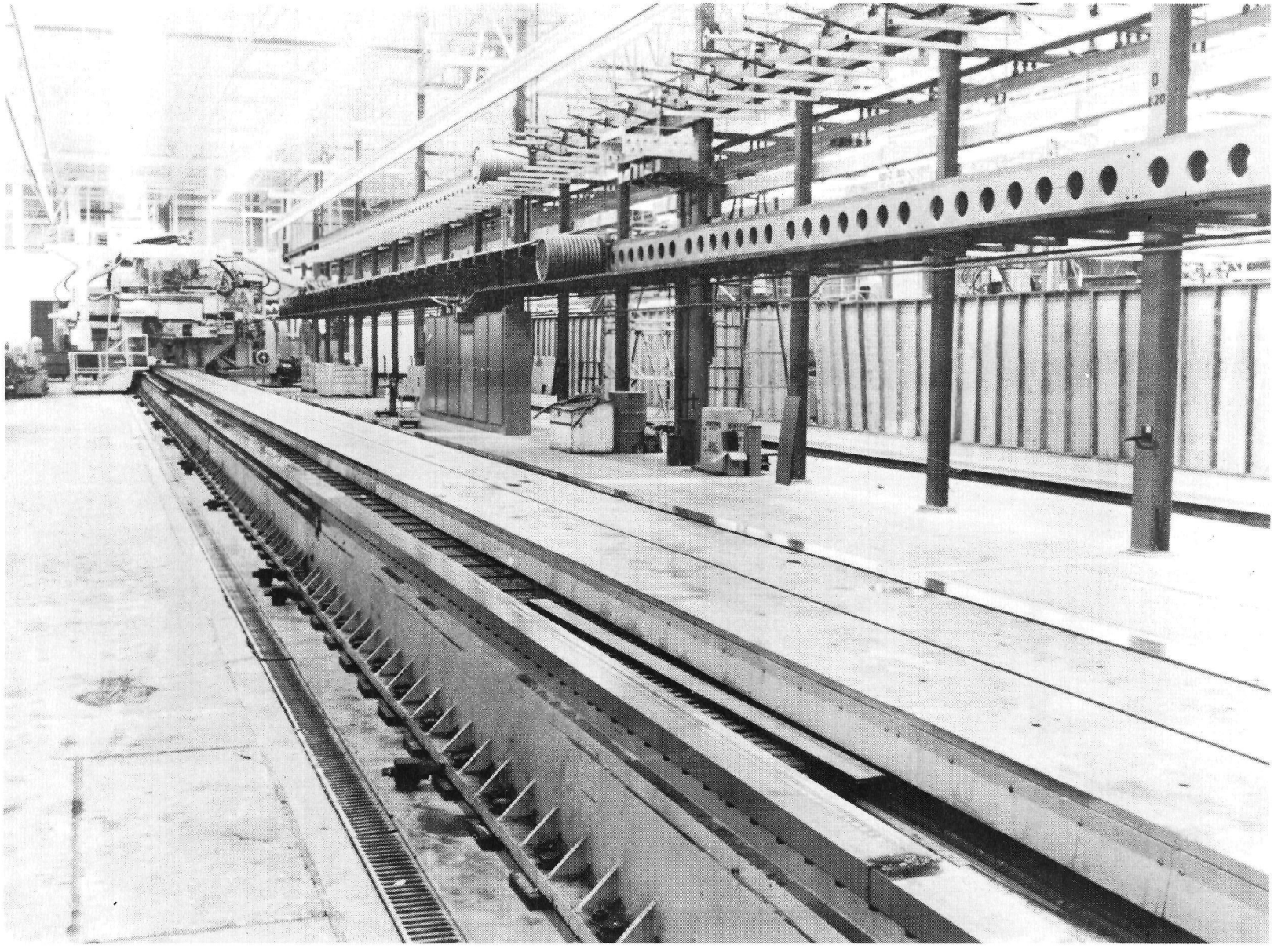


Figure 2-36. Cincinnati 7-Axis Spar Mill With 210-Foot Bed, LAD Structural Machining Center

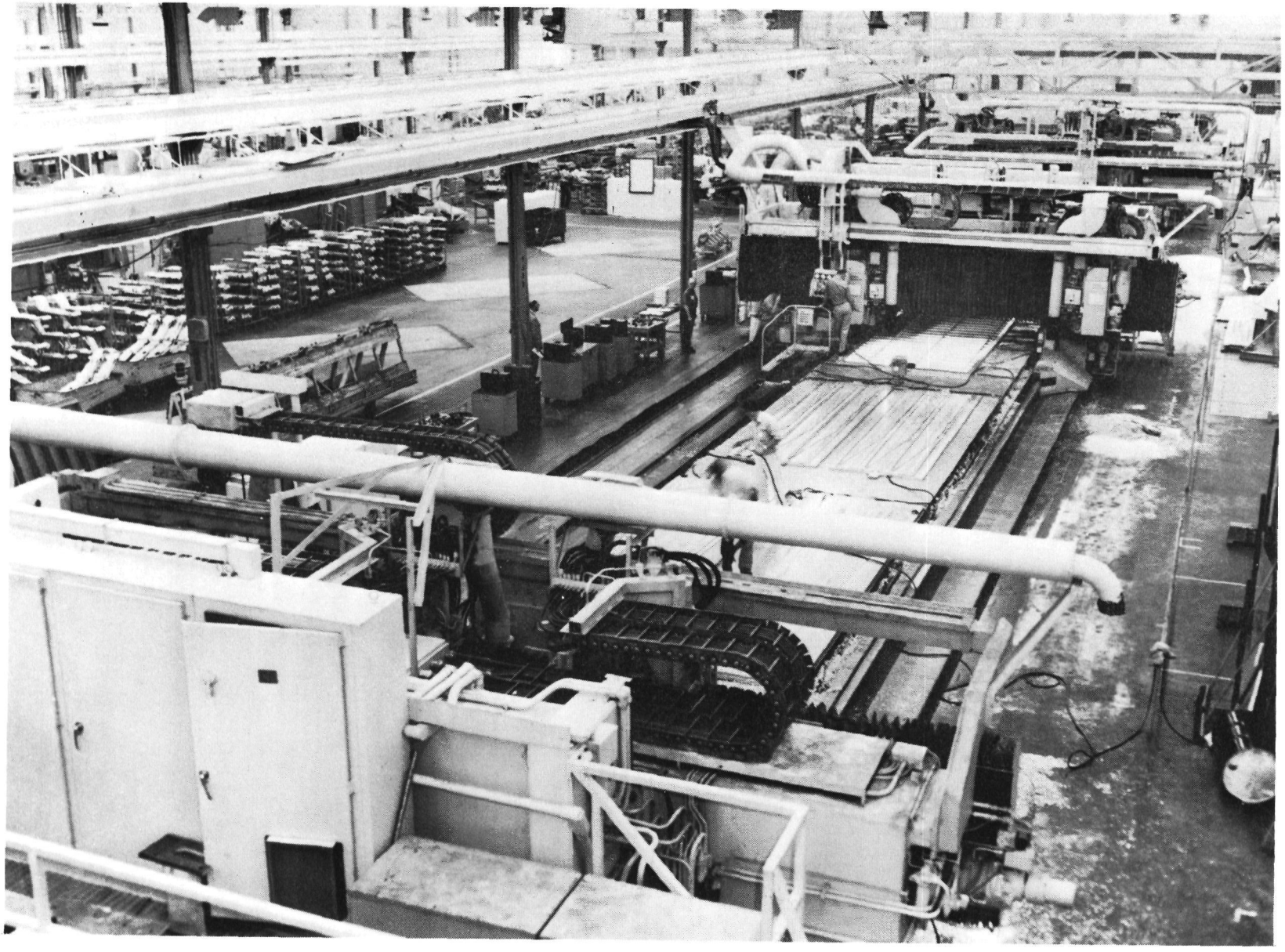


Figure 2-37. Numerically Controlled Skin Mill With 12- by 375-Foot Common Work Surface and 6 Gantries, LAD Structural Machining Center

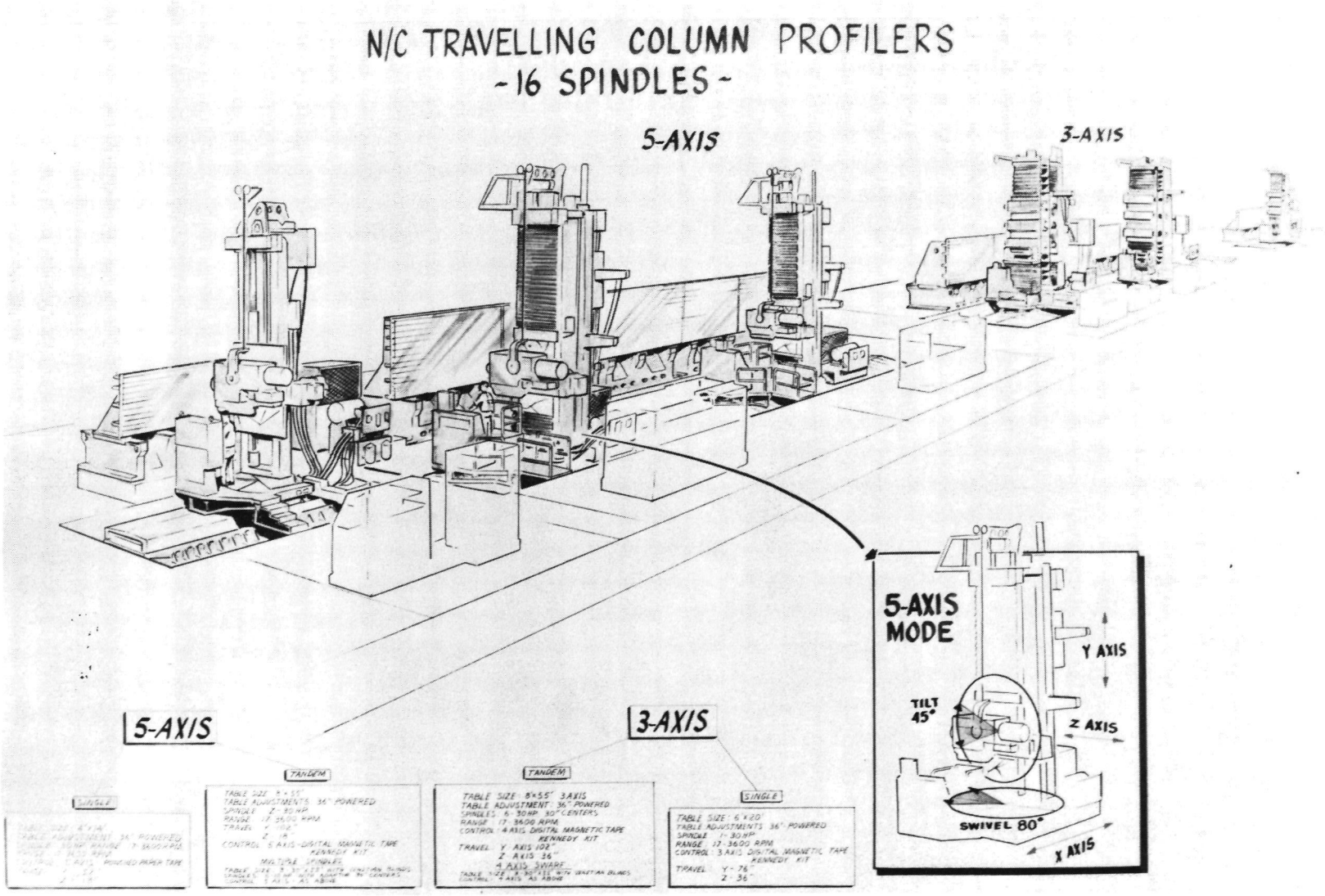


Figure 2-38. Numerically Controlled Traveling-Column Profilers, 16 Spindles

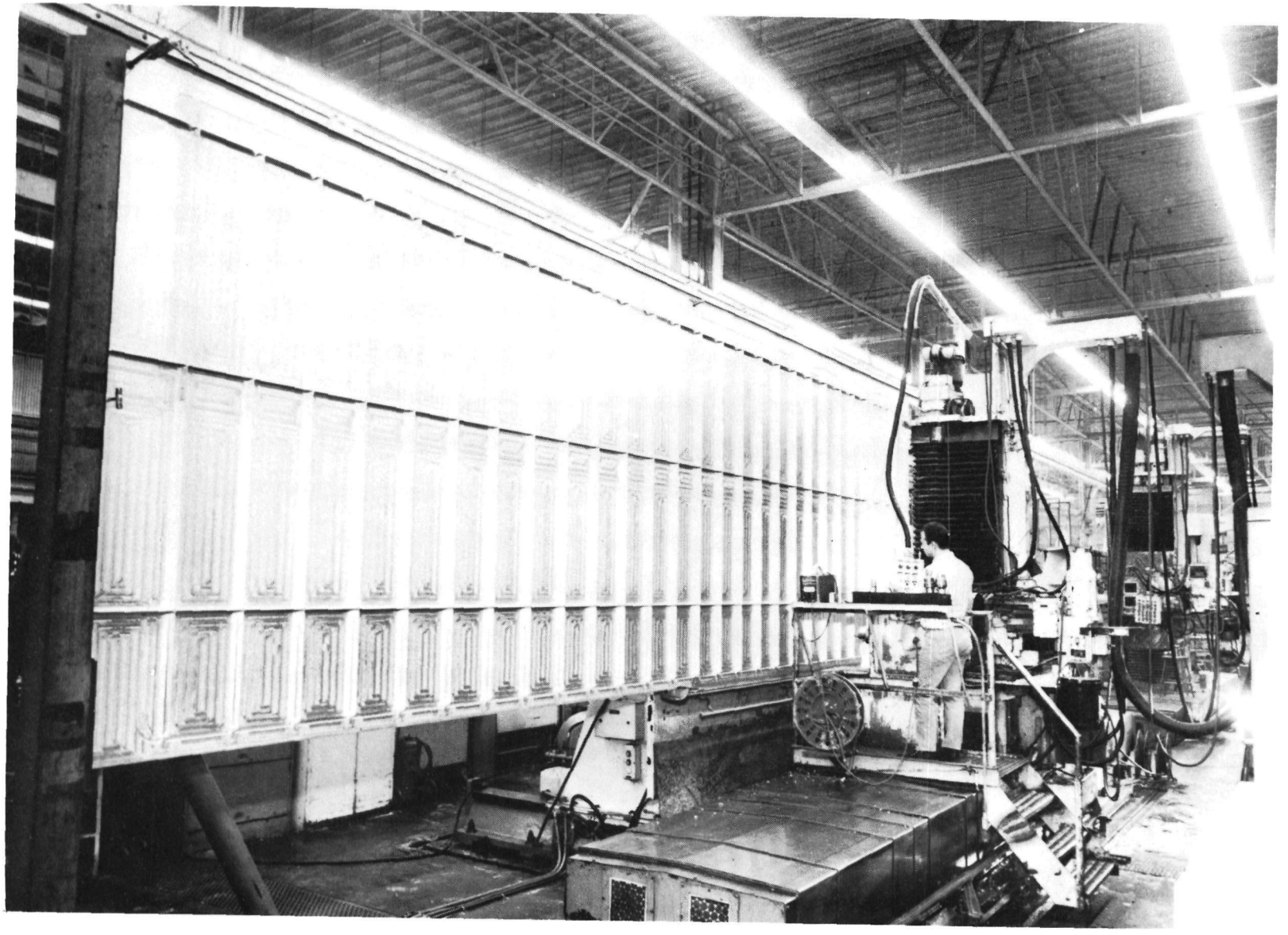


Figure 2-39. Structural Machining Center, LAD, Numerically Controlled Traveling Profiler (One Section)

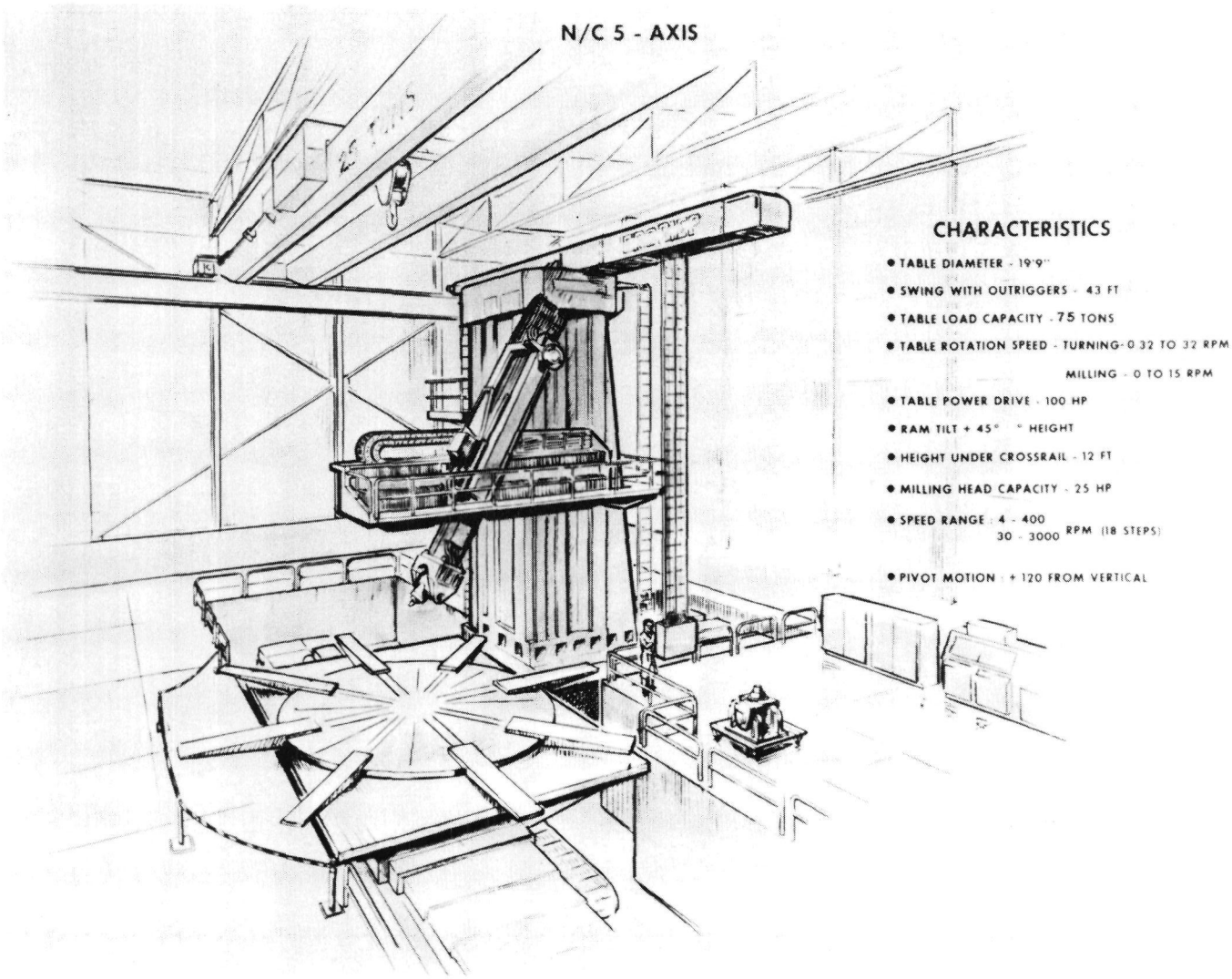


Figure 2-40. Froriep Numerically Controlled Vertical Turning, Boring, and Milling Machine, LAD Structural Machining Center

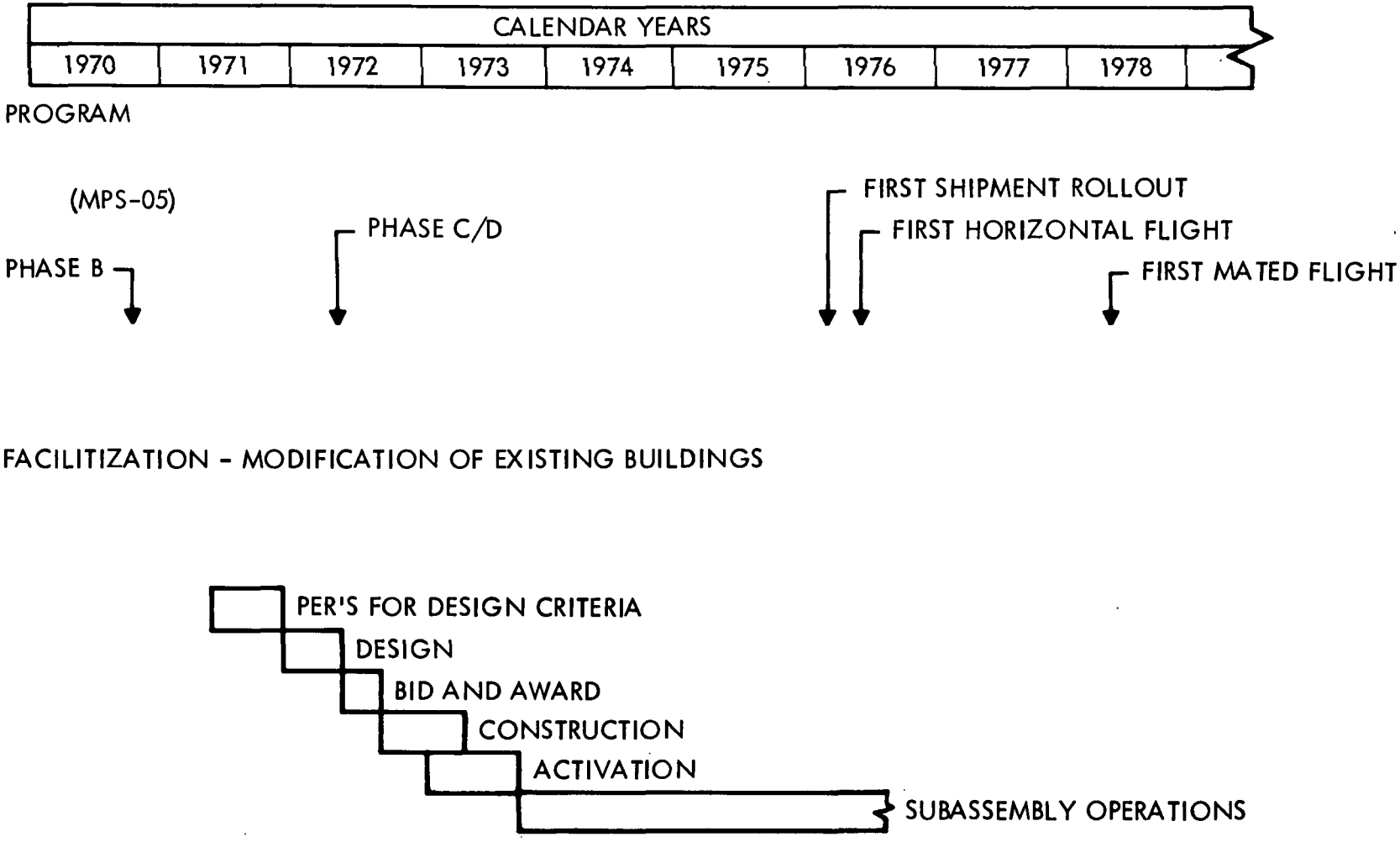


Figure 2-41. Seal Beach Building Implementation Schedule (Calendar Year)

Table 2-9. Major Facilities Required for Assembly and Detail Fabrication

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
CRYOGENIC TANK FABRICATION – SEAL BEACH			
Building S-02. NASA. Available, depending on S-II-type follow-on.	76,000-ft^2 manufacturing area. High bays have 10-ton bridge crane. Some areas environmentally controlled.	Removal of interior walls in high-bay area and rerouting of some utilities. Miscellaneous minor modifications. $60,000 (ROM est).	Existing building satisfactory. Facilities and equipment available for penetrant and X-ray inspection. Bulkhead hydrostat station usable with minor modifications. Large autoclave available.
INTERMEDIATE & FORWARD FUSELAGE ASSEMBLY – SEAL BEACH			
Building S-14. NASA. Available, depending on S-II-type follow-on.	30,000-ft^2 high-bay area with 20-ton bridge crane.	Minor modifications required. $25,000 (ROM est).	Existing building satisfactory. Adjacent Building S-018 has clean-room area for assembly of hydraulic systems prior to installation and areas on two upper floors for manufacturing support.
INTERNAL TANK INSTALLATIONS AND PAINT TOUCHUP – SEAL BEACH			
Building S-04. NASA. Available, depending on S-II-type follow-on.	9,200-ft^2 high bay 1,200-ft^2 test cell 10,400-ft^2 total.	Minor modifications required. $20,000 (ROM est).	Existing building satisfactory. In-tank entry platform readily adaptable for use. Exhaust systems available for paint touchup and spray-foam insulation application.

Table 2-9. Major Facilities Required for Assembly and Detail Fabrication (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
AFT FUSELAGE ASSEMBLY – SEAL BEACH			
Building S-03, Stations I, II, III, IV. NASA. Available, depending on S-II-type follow-on.	18,500-ft^2 high bay 17,400-ft^2 support area 35,900-ft^2 total. Two 20-ton bridge cranes with four 10-ton hoists.	The two south stations will require removal of the 16-foot-level platforms. Several other hinged platforms may be removed. Miscellaneous minor modifications required. $40,000 (ROM est)	Existing building satisfactory. Existing clean rooms for assembly of systems available. Environmental control facility systems are readily adaptable.
CLEANING OF TANKS – SEAL BEACH			
Building S-03, Stations V and VI. NASA. Available, depending on S-II-type follow-on.	5,900-ft^2 high bay area. Station VI contains 50-ton cab-operated bridge crane system with two 25-ton hoists. Station V contains two 70-ton cab-operated bridge cranes with two 35-ton hoists each.	Minor modifications required. $20,000 (ROM est)	Existing building satisfactory. Water-conditioning facility systems available for hydrostatic testing and cleaning. Vertical-travel rotating boom available for cleaning.

Table 2-9. Major Facilities Required for Assembly and Detail Fabrication (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
INTERMEDIATE AND FORWARD FUSELAGE SUBASSEMBLY – SEAL BEACH			
Building S-018. NASA. Available, depending on S-II-type follow-on.	66,700-ft^2 TOTAL area. 10-ton bridge crane coverage in 15,000-ft^2 high-bay area	Minor modifications required. $30,000 (ROM est)	Existing building satisfactory. Approximately half of area environmentally controlled. Contains 100,000- and 160,000-level clean rooms.
TOOLING AND MAINTENANCE – SEAL BEACH			
Building S-05. NASA. Available.	17,500-ft^2 area. 10-ton and 2-ton bridge cranes available.	None.	Existing building satisfactory.
MANUFACTURING AND QUALITY CONTROL OFFICES – SEAL BEACH			
Building S-01. NASA. Available.	37,000-ft^2 area.	Minor modifications required. $25,000 (ROM est)	Existing building satisfactory. Chemical laboratories and metallurgical laboratories available.

Table 2-9. Major Facilities Required for Assembly and Detail Fabrication (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
CREW MODULE FABRICATION – DOWNEY			
Building 290. NASA. Available.	46,000-ft^2 high bay area. 25,000-ft^2 support area 71,000-ft^2 total. 15-ton-bridge-crane coverage on west side, 35-ft hook height. 10-ton-bridge-crane coverage on east side, 55-ft hook height. 340,000-level clean room.	Remove two stacking stations. Modify tumbler. $50,000 (ROM est)	Existing building satisfactory. Area adjacent to high bay available for assembly of systems. Environmental control areas available.
TOOLING AND DETAIL FABRICATION – DOWNEY			
Building 1. NASA. Available.	260,000-ft^2 manufacturing area 351,500-ft^2 office area 611,500-ft^2 total.	$100,000 (ROM est)	Existing building satisfactory.

Table 2-9. Major Facilities Required for Assembly and Detail Fabrication (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
INTERMEDIATE FUSELAGE FABRICATION – TULSA			
Assembly Building 1. USAF. Available.	488,000-ft^2 manufacturing area 175,000-ft^2 office area 51,000-ft^2 laboratory area 714,000-ft^2 total. Temperature and humidity controlled. 15-ton crane coverage.	$50,000 (ROM est)	Existing building satisfactory.
OFFICE AND SUPPPORT AREA – TULSA			
Building 116. USAF. Available.	146,000-ft^2 area.	None.	Existing building satisfactory.
ASSEMBLY SUPPORT – TULSA			
Mingo Facility. Leased, City of Tulsa. Available, depending on Boeing 747 work.	241,000-ft^2 area. 5-ton bridge crane.	None.	Existing building satisfactory. 14-ft- and 9-ft-diameter autoclaves and supporting clean layup areas.
AFT FUSELAGE FABRICATION – COLUMBUS			
Assembly, Building 3. USN Available	750,000-ft^2 manufacturing area (215,000-ft^2 available) Temperature and humidity controlled. 5-ton crane coverage.	None.	Existing building satisfactory.

2.3 DEVELOPMENT TEST FACILITIES (GROUND TESTING)

This section describes the evaluation of sites and facilities to support each specific major test identified in the Preliminary Test Plan and recommends the method of implementation. Comparisons were made on the basis of existing facilities and modifications required or new facilities needed. Figure 2-42 shows the development test schedule. Existing or required facility equipment, special test equipment, and transportation capabilities were also included in the evaluation, as were operations and administrative considerations, including total program cost impact, schedule, conflicts in usage, and proximity to engineering.

2.3.1 Summary of Development Test Requirements

A summary of major ground tests is given in the following paragraphs to indicate the major facilities required to support the orbiter development test program.

Main Propulsion System Tests

Cluster firing of the two engines will provide an evaluation of the integrated propulsion system. A static firing of the complete orbiter vehicle will be conducted to verify readiness of the vehicle prior to mated flight.

Orbit Maneuver System and Attitude Control Propulsion System Tests

Integration of these two subsystems, which share a common propellant and pressurization system, will verify capability to perform hot firing at simulated altitudes.

Air Breathing Engine System Tests

Static firing of the jet engine mounted in a deployable pod will demonstrate integration of the engine, deployment mechanism, propellant feed, ducts, and other elements of the system.

Power Generation Subsystems Tests

Hot firing of the power generation system and integration of the power reactant storage and distribution, exhaust, pressurization and control systems with previously developed fuel cell, auxiliary power unit, and gear box under simulated electrical and hydraulic loads will demonstrate system capability. Full integration with the vehicle system will be accomplished at the horizontal flight test facility.

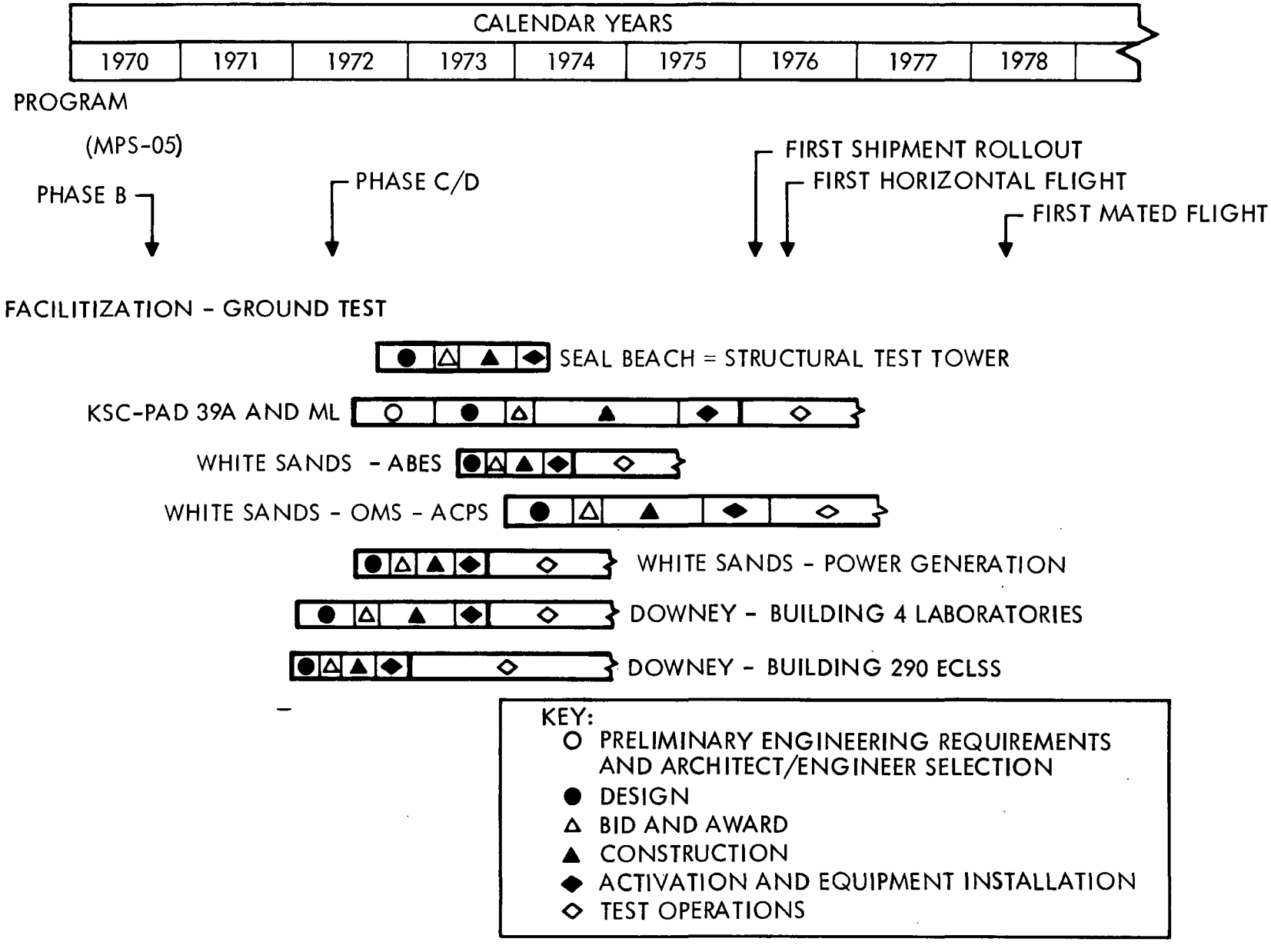


Figure 2-42. Development Test Facilities Schedule

Avionics Development Tests

Development of each avionics subsystem will be accomplished using breadboards and/or flight hardware. Integration of these individual systems with other vehicle systems during the development phase will utilize digital/analog hybrid computation to simulate input data. These systems later will be linked through the common data bus for avionics system integration. Final integration and verification of the avionics systems will be accomplished on the first flight vehicle.

Structural Tests

A series of static and dynamic tests are planned for major assemblies of the orbiter vehicle. The test articles will undergo limit and ultimate loads, acoustic, and fatigue tests to verify structural integrity. Tanks will be subjected to internal pressures, cryogenic temperatures, and external body loads to simulate the most severe mission conditions.

Ground Vibration Tests

Ground vibration tests are planned for the orbiter alone and for the mated orbiter and booster to obtain flutter natural frequencies. In either case, the vehicles will be supported horizontally on a low frequency suspension system while being subjected to low-force-level inputs.

Thermal Vacuum Test

Large complete structural sections of the orbiter containing electronic bays and partial subsystems will be exposed to vacuum cold soak and solar space environment to confirm heat balance calculations and to determine temperatures at critical equipment locations. Thermal control systems will be active where possible to simulate mission conditions.

Environmental Control Life Systems Support Tests

The environmental controls will be integrated in a flight type crew cabin to evaluate ability of the environmental control and life support subsystems to distribute air, control temperatures, and maintain oxygen-nitrogen balance as well as provide other life support functions.

Crew Escape Systems Tests

Ejection seats will be used on flight test vehicles to provide emergency egress. A high speed sled will be utilized for dynamics testing to demonstrate safe ejection utilizing an orbiter flight type crew compartment.

Table 2-10 summarizes the major development tests and recommended sites/facilities for performance of these tests.

2.3.2 Structural Testing

During the initial phases of design, and continuing through Phase D of the contract, a major portion of the testing of structural components, joints, panels, and other basic elements of the orbiter will be performed at the contractor's engineering development laboratories. These tests are to evaluate materials, methods of fabrication and processing, and to verify design concepts and integrity of structural elements and components. Close association of the design, test, and engineering and management functions during this critical phase of development requires that this effort be accomplished at the prime contractor's central base.

Design, development, and testing of larger and more complex components or structural subassemblies will be performed in specialized facilities within the government or industrial base, where more extensive capabilities exist for structural testing under various environments simulating operating conditions.

In the following sections, the analysis of facilities is described for each major structural test article or area of test.

Ground Vibration Test (GVT), Mated Vehicles

The ground vibration test will be performed on the mated booster and orbiter in a horizontal attitude before first mated flight. The booster will be supported on a low frequency suspension system (such as air bags) and multiple shakers will be attached to the structure of the vehicles. Data acquisition and control equipment will be portable. The test article envelope is 220 feet long, 150 feet wide, and 100 feet high.

The test can be accomplished at the maintenance and checkout (M&C) building at the launch operations site, either inside or outside the building. If inside, overhead bridge cranes would be used to place the orbiter on the booster; if outside, mobile cranes would be utilized.

Hydraulic jacks would be used to elevate the booster for installation of the suspension system. Portable platforms would provide access to the test vehicles. Available building utilities would support these requirements.

Because of the single need for accomplishing this test on one set of vehicles only, and the relatively short test period, an expenditure for more elaborate special facilities to accommodate the test is not recommended.

Table 2-10. Development Test Facilities

Major Ground Tests Orbiter	Test Requirements/Objectives	Facility Requirements	Site/Facility Recommendation	Comments
Main propulsion (MPS) cluster	• Integration test MPS Hot firing Engine out, engine gimbal Throttle, minimum power level	Static firing tower, LH_2 - LO_2 Propellants, pressurants, control center, Data acquisition, water cooled diffuser, orbiter handling, transportation	LC-19A, KSC Alternates: MTF MSFC	Modify mobile launcher to serve: 1. Cluster firing 2. Flight readiness firing Phase I Modify mobile launcher as second operational ML Phase 2
Flight readiness firing	• Verify all systems ready-mated flight			(Note: single engines developed and qualified at manufacturer)
Auxiliary propulsion	• Integration - OMS - ACPS - common propellant and pressurization system Hot firing Altitude simulation	Hazardous test site, LH_2 - LO_2. Propellants-pressurants, control center, Data acquisition, test stands, 5 to 10K thrust, altitude simulation, 75,000	White Sands Test Facility Alternate: Tullahoma Santa Susana CTL-III	Altitude capability, no LH_2 storage-, distribution Full capacity No altitude capability, acquisition being evaluated. (Note: single engines developed and qualified at manufacturer)
Air-breathing engine	• Integration of ABES with ducts, feed lines, deployment mechanism pod - instrumentation Hot firings	Horizontal static firing structure, JP fuel and distribution, control center, data acquisition, hydraulic service equipment, facility utilities	WSTF-Test Stand 301 Alternates: Santa Susana - Turbine Engine Test Facility Engine Manufacturer's Facility	Basic facilities exist. Modifications required. Preliminary discussions made with LAD on projected utilization
Power generation	• Integration PRDS, fuel cells, APU batteries Hot firing Simulated, electrical, hydraulic loads	Hazardous test site, test cells LH_2 - LO_2 propellants-pressurants, control center, data acquisition, load banks, facility utilities	WSTF - Test Stand 302 Alternates: Santa Susana CTL-IV	Basic facilities exist, minor modifications required
Hydraulics	• Integration of hydraulic subsystem full-scale mockup Interface with GN&C, DCM and D&C - (ASIL)	Hydraulic/control lab area, 160 x 60 x 35 ft adjacent to ASIL an d analog/digital computer plus hydraulic lab support, facility varidrive, control room	Bldg 004 Annex, Downey	Adjacent to ASIL and Engineering Computer Complex for end-to-end test of hydraulics system; also flight simulation potential
Avionics DCM, communications, D&C GN&C, EPD&C, instrumentation	• Individual development laboratories for each subsystem • ASIL for avionics integration • Adjacent to hydraulic controls and computer laboratories	Lab areas, 20,000 sq ft; power - 440 V, 3-phase ac; 120 V, 400 cycle; 28 V DC; air conditioning and avionics cooling, computer, RF telemetry ground station	Bldg 004, Downey Alternates: KSC MSC Subcontract	Adjacent to engineering computers, human factors laboratories, flight simulation lab, hydraulics controls lab, RF Ground Station in Bldg 016
Structures Body Aero surfaces	• Static and fatigue, major assemblies hot structures • Acoustic Tests, structural assemblies with partial systems installed	Structural test floor, 50,000 sq ft, 85 ft height, hydraulic load system and control, Radiant heat capability. Acoustic test facility.	MSFC - Bldg 4619, Major structures - Static/Fatigue Downey Lab - Bldg 288, smaller structures, static/fatigue, qualification for vibration, shock, acoustics, heat MSC - Houston, Acoustic Test Facility	Size of major structural test articles requires large structural test facility - existing at MSFC. Size of major acoustic test articles limited to dimensions of super guppy and NASA barge and NASA chambers.
Landing system	• Qualification tests, landing gear • Qualification, dray chute • Landing gear simulation tests	Special land gear test facility; First flight vehicle; Structural test lab and support equipment	Manufacturer or Wright-Patterson AFB Edwards AFB Bldg 288, Downey, Structures Lab Bldg 001, Downey	Wright-Patterson AFB: if vendor does not have full capability Taxi tests, first flight vehicle Labs equipped for functional mockup development
Docking and payload retrieval	• Working mockups			
Thermal control and thermal protection systems	• Development, materials, panels, processes • Verify analytical heat transfer predictions • Verify TPS assemblies and systems	Materials lab, structural test lab, and environmental labs (thermal chamber); special gas dynamics facilities	NASA - NR Test Labs and Materials Labs Environmental Chambers, Bldgs 288 and 004 NASA - Vacuum Chamber, Houston NASA - 10 Megawatt electro gas facility, Houston AF - 50 Megawatt gas dynamics, Wright-Patterson AFB	Large test specimens for environmental chambers A or B at NASA, Houston, will be limited in size by air transport vehicle (super guppy or equivalent)
Wind tunnel	• Extensive wind tunnel tests, Phases B, C, and D	Existing wind tunnels within the government/industrial base	Langley Research Center AMES Research Center AEDC Von Karman NR Los Angeles Division	Existing facilities adequate
ECLS	• Development and integration of crew cabin and life support systems	Bldg - clean room areas, bridge crane, special power, 440 V, 3 phase; 120 V 400 cycle; 28 V dc; breathing air O_2/ N_2, etc. ground cooling	NASA Bldg 290, Downey	All basic facilities available for development of ECLS pneumostatic test of cabin, test cell, Bldg 260, Downey
Tanks	• Pneumostatic tests, acceptance • Hydrostatic tests, acceptance • Cryogenic tests, qualification	Pneumostatic Test Facility Hydrostatic Test Facility Cryogenic Test Facility	NASA Seal Beach, Naval Weapons Station NASA Seal Beach, Station 6 - VAB NASA Seal Beach, alternates - Santa Susana Coca IV, MSFC - SI - C Stand, F-1 Stand	Minor modifications required. Modifications required. Modifications required - T. B. D.
Flight personnel CFE	• Development, qualification of crew escape and other CFE Full-scale dynamic testing	High-speed track facility; static test tower; structural test lab; lab areas for functional test and interface verification.	Holloman AFB, New Mexico Downey Structures Lab, Bldg 288	Sled test - all support facilities available. Tower available for 0-0 launch pad simulation.
Human factors	• Mockups • Simulators Dynamic simulation	0-g, neutral buoyancy facility Mockup, display area Simulation Facility	NASA - KC-135 -; NASA-MSC NASA Bldg 001, Downey NR Bldg 004, Downey; NASA-MSC simulation facilities	Shuttle display area existing Simulation lab and human factors laboratories, existing at Downey and MSC.
Horizontal flight test	• Verify flight worthiness	10,000-ft runway; hangars; tracking range; data acquisition; weight and balance; safing area	Edwards AFB NASA - FRC	Basic facilities exist for Category I flight test Point Mugu used for preflight prep and ferry to Edwards AFB

It is recommended that this test be performed at the launch operations site, utilizing the facilities to be provided. It is desirable to accomplish this test inside the building to avoid inclement weather. However, it can be performed outside the building without test degradation.

Ground Vibration Test (GVT) Orbiter

Test requirements and procedures are similar to GVT of mated vehicles. After installation of subassemblies, the complete vehicle will be subjected to low level, unit load vibration while supported on ground isolation pads. Test is to be accomplished before horizontal flight test and mated booster orbiter GVT.

Performance of the test can be accomplished at the final assembly site or at the horizontal flight test site. Building utilities would be available to support this test at either location. Hydraulic jacks would be used to support the vehicle during the installation of the isolation pads. A portable van would be used for data acquisition and control test equipment.

It is recommended that the test be performed at the final assembly site, where proximity of test equipment, personnel, engineering and manufacturing support will afford better efficiency than at the flight test site.

Static/Fatigue Test – Partial Vehicle and Major Assemblies

Static/fatigue tests will be conducted on major structural assemblies and on a partial vehicle under simulated heat conditions in critical areas. The partial vehicle test article will first be used for static structural test. Later, major sections will be disassembled for the installation of electronic and mechanical systems for acoustical testing. The size of the partial vehicle (consisting of intermediate fuselage, stubwing, full wing, and empennage) makes undesirable its transportation to another facility, even though ship and barge access is available. Primary consideration should be tiven to conducting these tests at the contractor's final assembly facility.

Three alternative plans have been evaluated to provide test facility capabilities:

1. An outdoor special test fixture and facility can be provided consisting of a test floor with flush-mounted, modular floor channels for attaching and reacting structural test loads. Heavy vertical columns to support horizontal loadcarrying trusses for the application of vertical test loads are required. A bridge crane for the handling of structural members in the buildup of a load structure to support a specific test also is necessary.

The test fixture could later be converted to a universal test jig for static/fatigue testing of other structures. Other requirements include a control room for personnel, instrumentation and data acquisition equipment, and hydraulic equipment and controls to provide fluid energy for the load cylinders. Standard facility utilities of power, water, and gas are also needed.

2. An extension to the Seal Beach final assembly building would require approximately 50,000 square feet, with a high bay over the vehicle 90 feet in height. A special structural floor and overhead crane would be required, as well as the control room and hydraulic distribution system mentioned above.

3. The structural test facilities in Building 4619, MSFC, Huntsville, have extensive structural test capabilities, including structural test floor with 500,000-pound-capacity anchor points, 20-ton bridge cranes, 80-foot hook height, and data acquisition equipment. A potential schedule conflict in the use of this facility exists since major testing of the shuttle booster is planned at this location.

Utilization of the facilities in Huntsville for conducting major static and fatigue testing of the partial vehicle is recommended:

1. All basic facilities exist requiring minimum modification.

2. Cost of a new special purpose facility at the final assembly site for one-time usage cannot be justified.

3. Transportation of the test article from Seal Beach to Huntsville using the NASA-AKD and a modified S-II transport is considered feasible.

Due to the size of the partial vehicle test article, one wing and the empennage would be shipped separately for assembly in Building 4619. Manufacturing assembly tooling and handling equipment would be utilized for these operations. The initial test would be the application of static loads to the aerodynamic surfaces for verification of analytical stiffness matrices. Next, the partial vehicle would then be tested in the conventional horizontal mode for both static and fatigue conditions. Testing of the forward fuselage section (integral LH_2 tank) is covered in a following section of this plan, Static/Fatigue Testing, LH_2 and LO_2 tanks.

Crew Module

Structural testing will consist of static/fatigue testing and pneumostatic testing of the crew module.

The paramount importance of the crew module requires that major phases of its design, manufacture, and development test be accomplished at the prime contractor's engineering-manufacturing base. Test facilities exist at the NASA Downey plant to support this development.

The Structures Laboratory in Building 288 has a 60- by 180-foot structural test floor with floor beams capable of reacting loads of 7,500 pounds per lineal foot and a truss chord height that can accommodate structures up to 45 feet. A large range of hydraulic tension and compression load cylinders are available, with hydraulic control equipment to provide multi-pressure static dynamic loads. Instrumentation, including load cells, deflection transducers, and strain recorders are available for performance of these tests (Figure 2-43).

Pneumostatic testing and leak check of the crew module can be conducted in the test cell of Building 260 at the Downey facility. Basic facilities, including controls, instrumentation and data acquisition equipment exist (Figure 2-33). Test pressure and volume of the test article meet safety requirements. TNT equivalent is well below the rated capacity of the test cell (50 pounds TNT).

It is recommended that structural testing of the crew module be accomplished at Downey. Existing facilities are well suited for static and fatigue testing. Building 288 can be used without modification.

For pneumostatic testing at Building 260, the size of the test article requires modification to the test cell. The cell should be increased in height by approximately 10 feet and the slide hatch elevated accordingly. Existing access platforms and stairs should also be modified to the configuration of the test article.

The performance of structural testing of the crew module should be accomplished at the prime contractor's central engineering manufacturing base. Existing facilities are well suited to accomplish this task.

Environmental Testing—Components and Assemblies

Development qualification of structural elements, components, and assemblies will require various environmental conditions of vibration, acceleration, shock, acoustic pressure, heat, and cold to verify the integrity

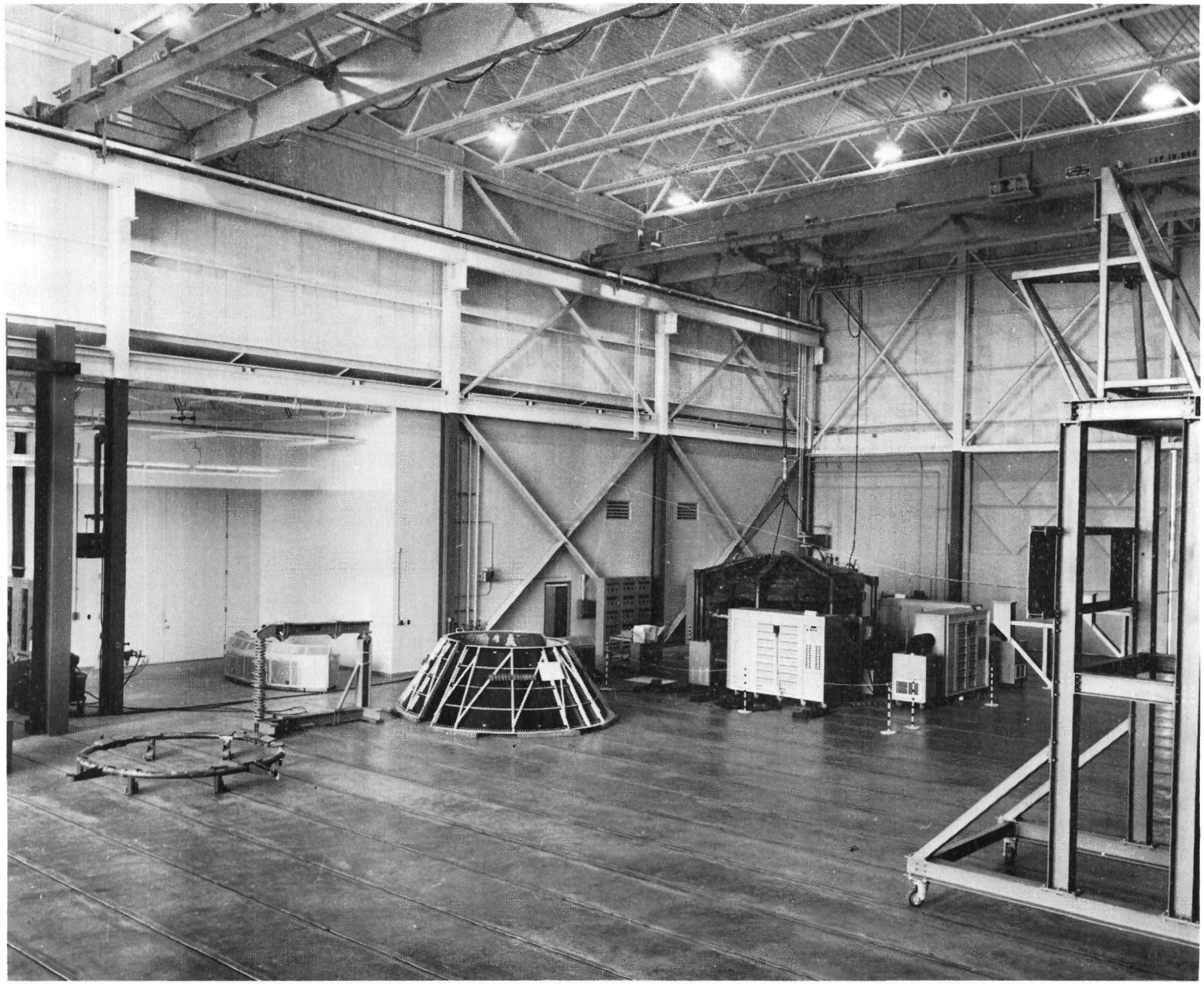


Figure 2-43. Structures Laboratory, Building 288

of these test structures to sustain their operational life. Size and complexity of these test specimens will require facilities of varying capabilities to accomplish these tests (Figure 2-44).

The dynamic simulation laboratory in NASA's Building 288, Downey, is designed to handle both small and large components and structures. This laboratory is equipped with the shakers, centrifuges, and drop test machines to subject the test articles to sinusoidal and random vibration, acceleration and shock. Equipment exists to analyze, reduce, and print out test data automatically. This laboratory is also supported by a radiant heating facility with control and recording channels with a total capacity of 6000 KVA.

Acoustical testing of smaller sized components could be accomplished at the acoustical test laboratory in Building 288. It contains equipment with broadband random frequencies of 37.5 to 9600 Hz at sound levels up to 170 dB. The test chamber volume is 190 cubic feet.

Acoustical tests of larger components can be accomplished at the NR Los Angeles Division acoustical facility. This chamber is capable of receiving a test specimen up to 18-by 15- by 14-feet, and can simulate the noise levels and frequencies equivalent to the orbiter main propulsion engine during launch and flight.

For the acoustical testing of large specimens, such as the crew compartment, intermediate and aft fuselage assemblies, the MSC Spacecraft Acoustical Laboratory at Houston can be utilized. Specimens used in the structural test program could be reused for acoustic tests to measure response of the structure for comparison with analytical predictions. Also selected electronic and other vibration-sensitive equipment can be installed in these structures to observe their ability to withstand the induced environment. The fuselage sections would be shipped by barge from Huntsville to Houston. The crew compartment would be shipped by Super Guppy from Long Beach. No modifications to the basic facility are anticipated.

The broad capabilities of the engineering test laboratories at Downey and the equipment of the environmental test section of the laboratory provide a facility well equipped to support the various aspects of structural testing.

As specimens become larger and more complex during later phases of the program, the other specialized facilities discussed above can be used. Figures 2-45 through 2-48 are typical examples of the Downey laboratories.

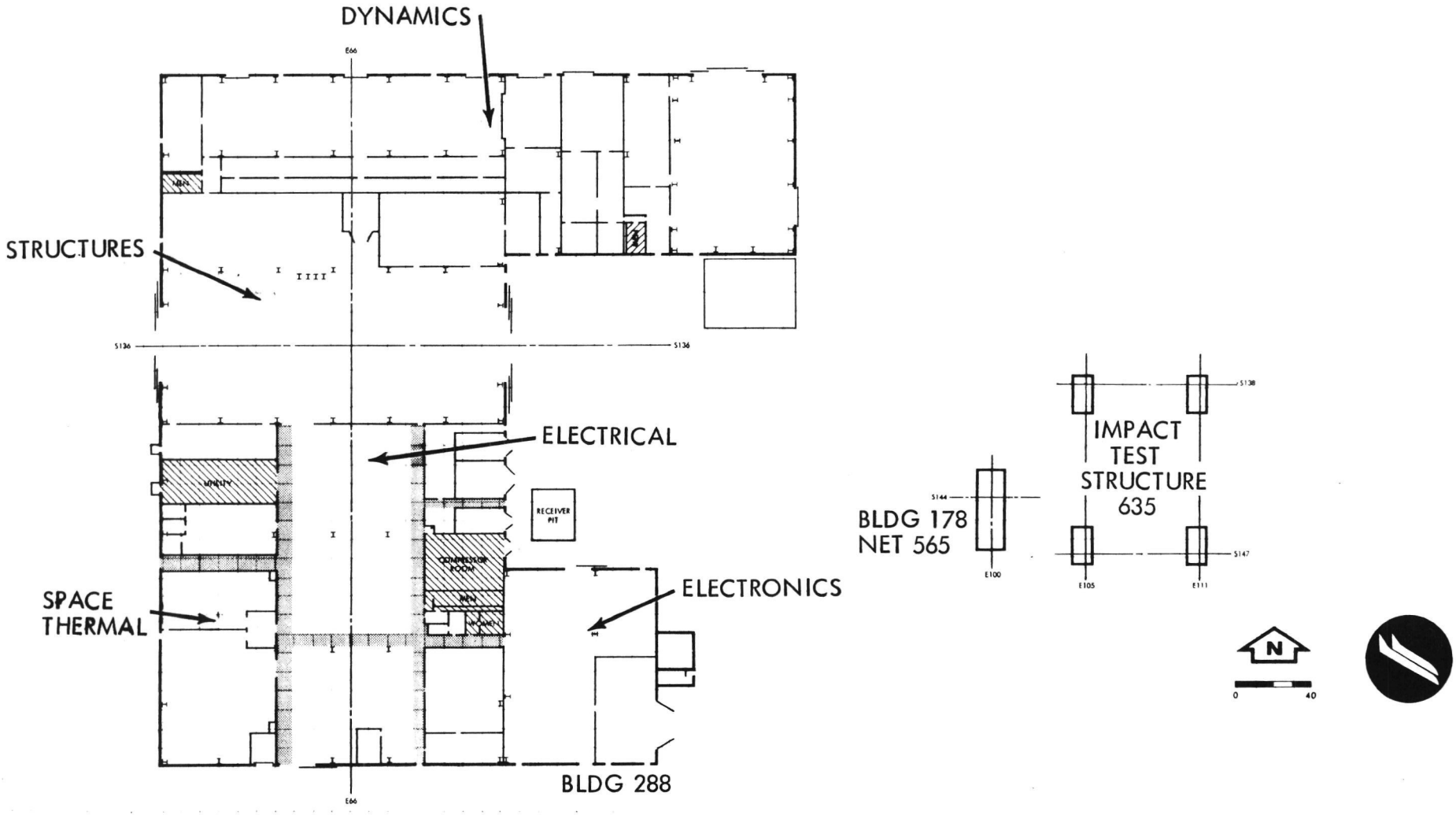


Figure 2-44. Test Laboratories, Building 288

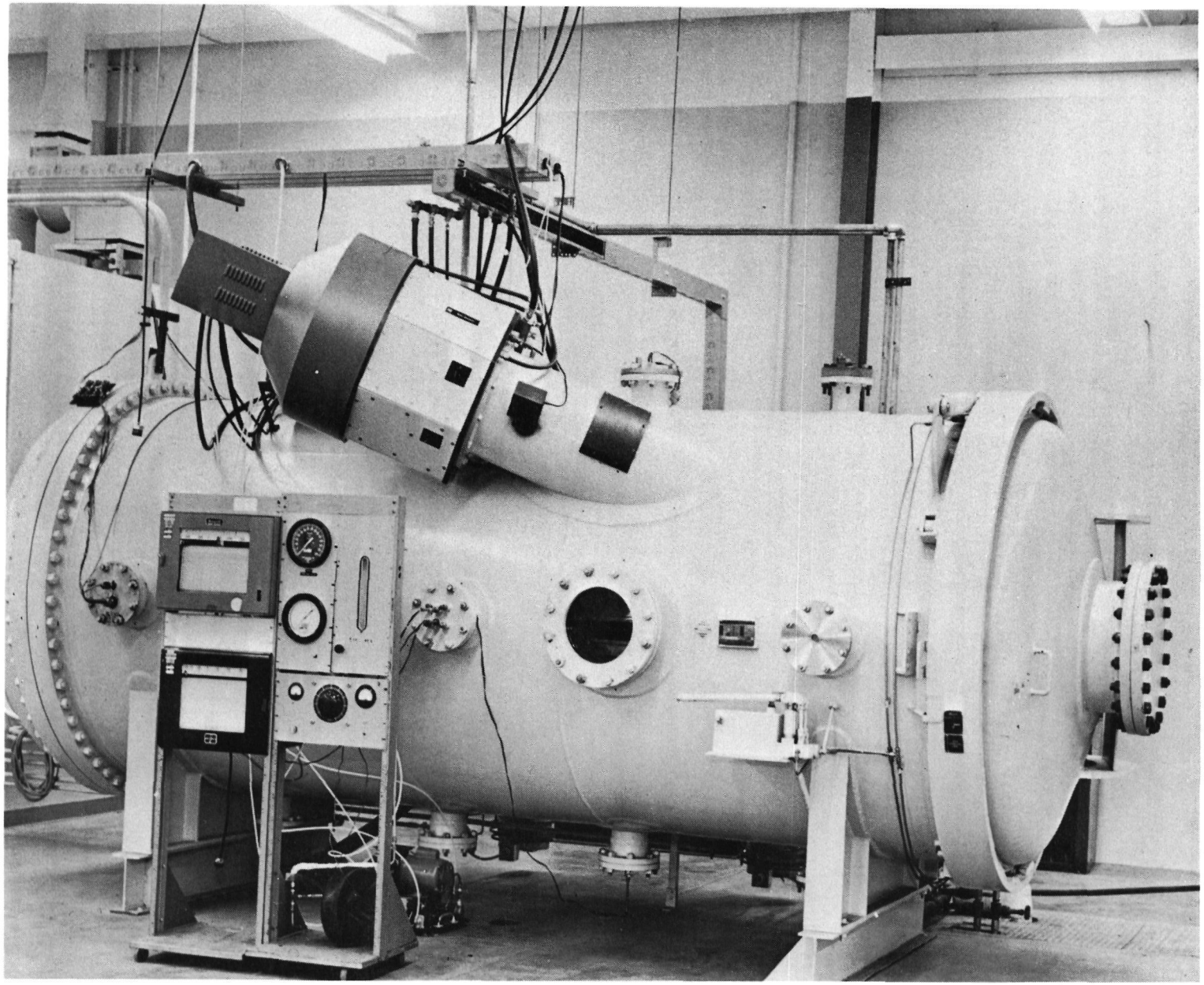


Figure 2-45. Thermal-Vacuum Chamber

Figure 2-46. Materials and Processes Laboratory

Figure 2-47. Materials and Processes Lab

Figure 2-48. Dynamics Laboratory

Hydrostatic, Pneumatic, and Cryogenic Testing of LH_2/LO_2 Tanks

Acceptance testing of the main propellant tanks will consist of hydrostatic testing of bulkheads, pneumostatic testing of complete LH_2 tanks, and hydrostatic testing of complete LO_2 tanks.

Capabilities exist at the NASA Seal Beach facility for performing bulkhead hydrostatic testing, although new tooling for the various sized bulkheads will be required. Full tank pneumostatic testing can be accomplished at the existing pneumostatic test facility at the adjacent Naval weapons station with minor modifications required. Hydrostatic testing of LO_2 tanks can be accomplished in Station 6 of the VAB with modifications.

Qualification testing of the LH_2 and LO_2 tanks will use LN_2 as the cryogen and will require a special facility to accomplish this phase of testing.

A site with an LN_2 storage and distribution system, structural test tower, tank handling derrick, control center, hardstand, retention dikes, and transportation access would be required.

The S-1C and F-1 Test Stands at Huntsville and the static test tower at Seal Beach have been considered for this test.

Use of the Seal Beach facility is recommended for the following reasons:

1. Greater cost effectiveness

   a. less cost for modification of structure.

   b. less transportation and handling costs.

2. Potential schedule conflict with booster in use of the S-1C and F-1 Stands at MSFC.

Moderate modification of the Seal Beach tower will be required. An LN_2 storage and distribution system, a retention dike, and a radiant heat capability for structural heat simulation will be the necessary major facility additions. Mobile cranes can be used to place the test articles in the test stand.

Alternative sites for this testing could be Santa Susana (COCA IV area) or the MSFC S-IC test stand or other test stands.

2.3.3 Propulsion Systems Testing

Main Propulsion System

The development test program for the main propulsion system will consist of a full integration test of the tanks, feed system, government-furnished rocket engines, and gimbaling system. The test article will consist of a partial vehicle equipped only with enough subsystems and hardware to accomplish the cluster firing program. This test article will later be returned to the final assembly facility for refurbishment and use on a flight vehicle.

Basic facility requirements to accomplish the integration testing will include a test site equipped with propellants, pressurants, test stand, control center, fluid distribution system, instrumentation, and operational items necessary to support cluster firing.

Seven sites from both the government and industrial base were considered in a facilities trade study. A comparison summary is shown in Table 2-11.

Because of quantities of propellant and thrust of the main propulsion system, four of the candidate sites were unable to perform the required cluster firing test program.

Edwards Rocket Site was also eliminated due to the high cost of route clearance for transportation of the test article and the lack of an LH_2 storage and distribution system.

Integration testing of the main propulsion system was considered feasible at MTF, MSFC, and KSC.

At MTF, modifications are required to the A-1 and A-2 test stands due to the size and configuration of the test article. The existing superstructure would require replacement with a structure simulating support for the orbiter at the booster mating points during static firing. The main derrick support structure would require elevating to provide sufficient height to place the test article in the stand.

Water-cooled diffuser nozzles would be provided to permit throttling of the engines to minimum power and modification made to the firex and deluge systems to accommodate this configuration.

Table 2-11. Propulsion Systems Candidate Test Site Comparison

Facility Item/ Consideration	Shuttle Requirements	Candidate Sites Capabilities and Limitations						
		Santa Susana Field Lab	Edwards Rocket Site	Nevada Test Facility	White Sands Missile Range	Mississippi Test Facility	Marshall Space Flight Center	KSC
Test Stand	550,000-lb thrust mps orbiter 1800 lb thrust ACPS 18,000-lb thrust ABES 10,000-lb thrust OMS	COCA I COCA IV adequate CTL, 3, 4, bowl area adequate OMS, ACPS, ABES	4 F-1 stands adequate MPS	Not adequate Main propulsion OMS, ACPS, ABES OK	Not adequate Main propulsion OMS, ACPS, ABES OK	A-1, A-2 stands adequate	S-IC stand adequate	LC39 basically adequate
Facility Utility System	Power, deluge water, derrick, cranes	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
Control Center Data Acquisition		Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
LH_2 LO_2 Storage Supply	LO_2 200,000 gal. Main LH_2 500,000 gal. Prop	Adequate	LO_2 adequate No LH_2 system	LO_2 adequate No LH_2 system	LO_2 adequate No LH_2 system	Adequate	LO_2 adequate No LH_2 system	Adequate
High Pressure Gas Systems	GH_2 distribution GN_2 purge and valve act. GN_2 tank purge	Adequate	GN_2 adequate No GH_2, GHe Limited	Limited	GN_2 adequate No GH_2, GHe Limited	Adequate	GN_2 adequate GH_2 limited	Adequate
Safety Noise Limitations	Propellant/TNT equivalent Distance separation Community noise Problem	Limitations Noise and propellant weight MPS ABES, OMS, ACPS OK	Adequate No limitations	Adequate No limitations	Adequate No limitations	Adequate No limitations	Adequate No limitations	Adequate No limitations
Transportation Access Test Article	Barge Super Guppy Special highway transport	S-II type transporter MPS OK ACPS, OMS, ABES	Limitation Main propulsion tanks OK ACPS, OMS, ABES	Limitation Main propulsion tanks OK ACPS, OMS, ABES	Limitation Main propulsion tanks OK ACPS, OMS, ABES	S-II type Barge transport	S-II type Barge transport	S-II type Barge transport
Proximity to Engineering Support	Within living/driving range	Adequate	Adequate	Relocation required	Relocation required	Relocation required	Relocation required	Adequate
Relative Cost Modifications and/or New Facility		Moderate modifications	Major modifications LH_2 storage and distribution sys	Major modifications	Major modifications LH_2 storage and distribution sys	Least modification	Major modifications LH_2 storage and distribution sys	Minimum modifications
Note: Adequate (meets program requirements)								

The other basic facilities, including LH_2-LO_2 pressurants and propellants deluge system, control center, instrumentation and data acquisition equipment and facility support services and systems currently exist, requiring minimal modification. The NASA barge-transportation system allows access of the test article.

At MSFC, modification of the S-IC test stand would be similar to, but less extensive than that at MTF. An LH_2 storage and distribution system would be required. Other basic facilities are considered adequate and can be readily adapted. The test article, smaller than an S-IC, can be barged to MSFC.

At LC-39, KSC, an existing mobile launcher (ML) would be modified to serve in a single configuration both for cluster-firing in developmental test and later for flight-readiness firing of the completed orbiters. This same launcher would become the second operational ML.

Modifications include the installation of a steel structure mounted on the base of the ML to support the orbiter at the booster interface points. Other modifications include the installation of water-cooled diffuser nozzles to permit throttling of the engines, the provision of a wet-type flame deflector to sustain full-duration firing, and modification of the flame trench spray system.

Fill, drain, and vent lines and other controlling and monitoring systems would be routed on the operational umbilical arms utilizing a substantial portion of the operational support equipment during cluster firing.

Installation of the test article on the ML would be done in the VAB with transportation by the crawler to the pad. Transportation to KSC would utilize the existing Saturn V ship and barge system.

It is recommended that the cluster firing program be performed at KSC. Common utilization of facilities and support equipment at KSC for the test as well as the flight readiness firing test provides the greatest program cost effectiveness. The cost of activation and deactivation of a separate test site for the relatively short cluster firing program would also be avoided. MTF is well qualified if operations construction schedule, hazards analysis, or other constraints arise.

The mobile launcher and Pad 39A would be modified as described and illustrated in Figure 2-49.

Schedule for implementation would require twenty-four months: nine months design, twelve months construction, and three months for activation.

Air-Breathing Engine System (ABES)

Development testing and integration of the complete ABES system will first require an engine test site for integration of the engines with fuel

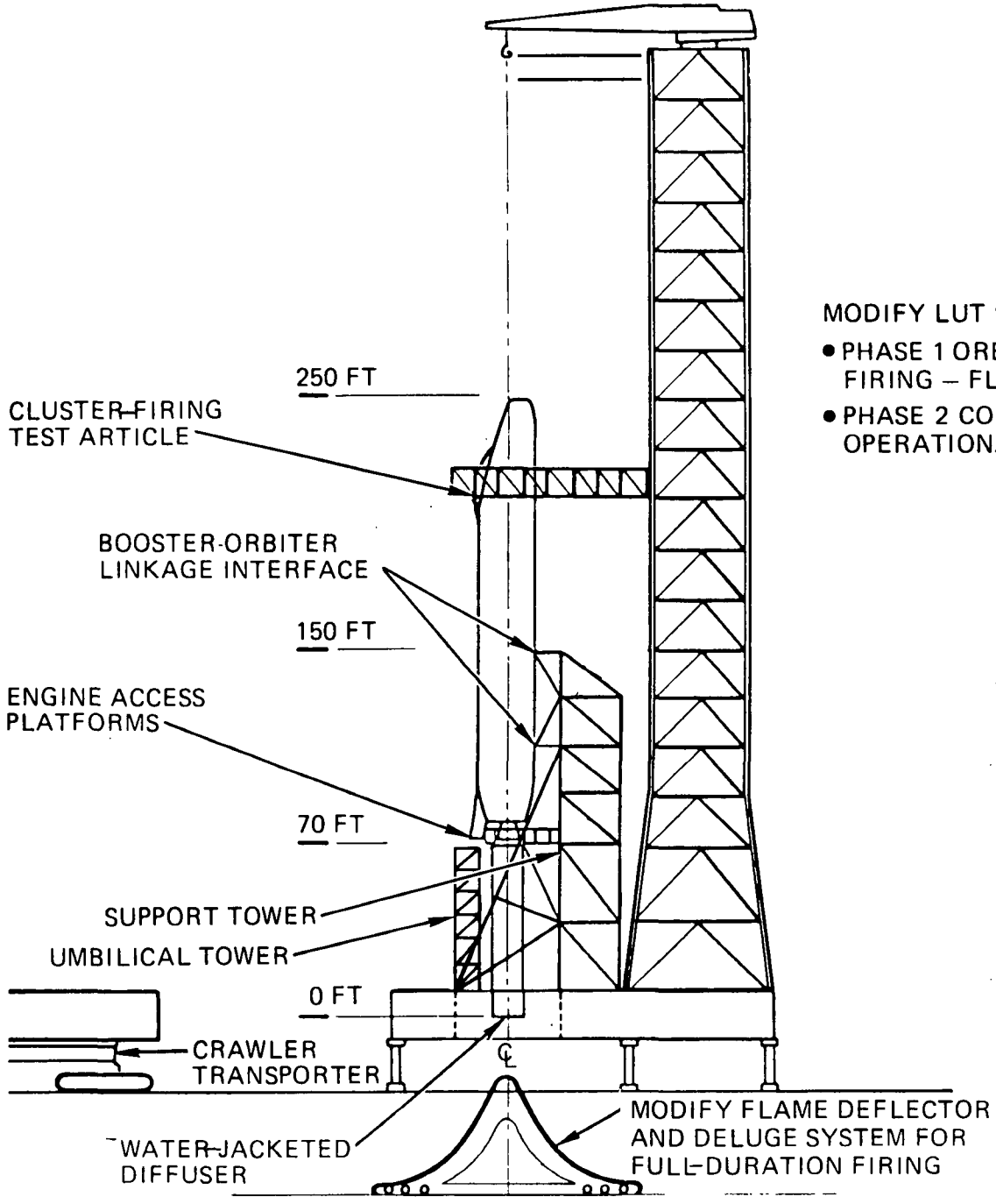


Figure 2-49. Static-Firing Concept at KSC

system, nacelle inlet ducts, deployment mechanism, starters, and controls. Complete integration of the ABES will be accomplished on the first flight vehicle.

Ground testing for integration of the ABES could be accomplished at the test facilities of the engine manufacturer or at prime contractor's test site where specialized facilities exist for the testing of JP-fueled jet engines. NR's Santa Susana Field Laboratory has a special air breathing propulsion test complex specifically equipped to conduct this type of testing.

Also under consideration is the use of Test Area 300 at the White Sands Test Facility. Although this complex has been facilitized for liquid rocket engine testing, the basic facilities are adaptable to ABES development testing.

Modification at either Santa Susana or White Sands would include adapting the engine thrust structure to the test stand thrust mount and the provision of structural support members for other components of the test article.

At White Sands, Test Stand 301 could meet test requirements with relatively minor changes to the facility. The single engine could be fitted to the stand thrust structure to permit horizontal firing over the flame trench. Volume of the main and auxiliary test article tanks is sufficient to support this test without the need of an on-site jet propulsion storage and distribution system. Existing data acquisition equipment at the control center exceed requirements.

Use of White Sands for ABES integration is recommended due to minor changes required at Test Area 300 and the potential effective utilization of personnel and facilities when combined with other orbiter development tests also planned at White Sands. (See Auxiliary Propulsion and Power Generation.)

Orbit Maneuver System (OMS) and Attitude Control Propulsion Systems (ACPS)

Development of the single OMS and ACPS engines will be accomplished at the respective manufacturer's facilities.

These two systems utilize common LH_2 and LO_2 tanks. The criteria for long duration cryogenic storage require extensive development of dewars and high performance insulation to demonstrate performance and verify design before development of the full scale tanks.

Criticality of development of these tanks requires that this effort be accomplished at the prime contractor's engineering development laboratories.

NR's Downey facility has the necessary cryogenic fluids laboratory with test cells, control rooms, instrumentation, and data acquisition equipment. Auxiliary laboratories exist with environmental chambers, vibration equipment, and support technical services to perform this development.

Combined systems testing of OMS and ACPS will be accomplished at a hazardous test site for full integration of the two systems. Three sites have been considered for these tests: Santa Susana, White Sands, and Tullahoma.

The NR Santa Susana Field Laboratory with Component Test Laboratory III has the basic requirements to support these tests, but would have to be supplemented with an altitude simulation capability if this becomes a firm requirement.

The AEDC facility at Tullahoma was considered primarily because of its extensive altitude simulation capability. Due to its planned heavy involvement in development of the Space Shuttle engine and other government programs during the required time frame, a potential conflict would exist in its utilization.

The White Sands Test Complex 400 has the basic facilities to perform all phases of the combined systems test. Also, two large space simulation chambers exist that could satisfy the hot firing of the engines at simulated altitude conditions. An LH_2 storage and distribution system is now in the planning stage and could be available to support this testing.

From the standpoint of existing and planned facilities, White Sands is considered best qualified to fulfill all potential test requirements and is therefore recommended as the site for performance of these tests.

Implementation of the combined systems test would be accomplished using the Ambient Test Stand 402 for installation of a complete OMS system with Test Stands 401 or 403 to be used for installation of one set of ACPS engines. Use of a modified combustion chamber will permit atmospheric firing of the OMS engines. Use of TS 402 or 403 will provide simulated altitude firing of one group of ACPS engines and will represent the extended piping run to the accumulators and the group of engines located in the nose section of the orbiter.

The test article consisting of three OMS engines, gas generators, heat exchangers, turbopump assemblies, a complete set of LO_2 and LH_2 tanks and their connecting feed lines and pressurization system would be provided

(mounted on a boilerplate support structure), to simulate the physical location and relationship of components as installed in the flight vehicle. Also as part of the test article, two groups of ACP engines will be included with their accumulators, piping, and controls. To simulate full flow conditions of other ACPS engines not represented in the test article, orifices will be utilized with gas flow to vent and burn stacks.

Primary modification would include the relocation of an existing LH_2 dewar, installation of a fluid distribution system, vent and burn stacks, and modification of the test stand enclosure and support structure to accommodate the test article. Relocation and/or enlargement of the flame deflector might be required to suit the test article engine configuration. A detailed analysis will be required to determine the full extent of total modification. Existing facility controls and instrumentation should be adaptable to the new test requirements, requiring minimal modification or additions.

Special support equipment requirements include a hydraulic power unit for gimballing engines, a thrust measurement system, and a computing capability for simulation of interface subsystems, data acquisition, and control of the test article. See Preliminary Test Plan, Section 6.4 for details.

2.3.4 Avionics Development Testing

Development and qualification of individual components of the various avionics subsystems will be carried out at the respective subcontractors' facilities. Integration testing of each subsystem will be accomplished at the prime contractor's engineering laboratories.

The test article for each avionics subsystem will consist of flight hardware and/or breadboard assembly of components. Integration of these individual systems with other vehicle systems during the development phase will ensure system compatibility. Input data for initial development will be simulated with digital-analog-hybrid computations. Later in the development phase, these systems will be linked through the common data bus for integration of the avionics subsystems with DCM hardware.

Integration of avionics subsystems will be accomplished in the avionics laboratory. Interfaces between the avionics laboratory, hydraulics/controls laboratory, and flight simulation laboratories require contiguous areas.

Subsystem elements required to be accommodated within the avionics laboratory include Data and Control Management, Guidance, Navigation, and Control, Communications, Displays and Controls, Electrical Power Distribution and Control, and Development Flight Instrumentation.

Other interfaces that require adjacency to the avionics laboratory are other laboratories associated with the hydraulic system mockup, computing center, simulation laboratory, and human factors laboratory.

Antenna Pattern Testing

An antenna pattern range is required to evaluate impedence characteristics, pattern effects of thermal protection system (TPS) materials, obstructions on the orbiter, subcontractor's antennas and to verify pattern data. Requirements for an antenna test range include:

1. Ambient noise not to exceed minus 40 dbm from 2.5 GHz to 17 GHz.

2. Range should be free from reflecting metallic objects, buildings, and severe variations in the ground plane.

3. Pattern model should be in view of operating personnel.

4. Range depths should be variable, with depths of 50 feet to 500 feet for 1/10 scale model measurements.

5. Regulated facility power.

6. Easy access between range and associated electronic laboratory.

Major facility items include the property, antenna pedestals, polar positioners, and control room. Major equipment items include wide range receiver, recorders, contour plotter, integrator, transmitter, dishes, and signal generators.

Space Division antenna capabilities include antenna and model towers, polar positioners, two model lifting platforms, three operations consoles, oscillators, receivers, recorders, signal generators, servo-driven typewriter, paper tape punch and reader, and radiation distribution printer. Upon contract award, this equipment would be activated for shuttle support at an NR Southern California plant site.

More specific definition of antenna test plans will be required before a complete evaluation can be made. Most desirable is a range owned and operated by contractor personnel.

2.3.5 Electrical and Hydraulic Power Generation Systems Testing

Major ground development testing of the power generation system includes the integration of main components to verify performance under specified conditions, the integration of the power system with other vehicle systems, and hot firing demonstration tests.

Test hardware for the ground development testing will consist of LO_2-LH_2 storage tanks, batteries, fuel cells, auxiliary power units, and their interconnecting electrical and fluid distribution system and controls.

The primary facility requirements for accomplishment of these tests will be a test area equipped with propellants, test cells, and other technical support items for cold flow and hot firing of the system.

NR's Santa Susana test facility, with minor modifications, satisfies the requirements. Components Test Laboratory 4 has the test cells, LH_2-LO_2 storage and distribution system, purge gases, facility utilities, control center, and general-purpose data-acquisition equipment.

White Sands Test Stand 302 could also be utilized for these tests. The provision of portable LO_2 and LH_2 dewars would be required. Other facilities can be used with minimal modifications. Hydraulic and electrical load banks would have to be provided to simulate operational condition.

The use of White Sands Test Stand 302 is recommended for development testing of the power generation systems due to the initial low cost of implementation and the potential effectiveness when combined with other systems planned for testing at White Sands. (See ABES and OMS-ACPS Testing.)

2.3.6 Environmental Control and Life Support Systems (ECLSS) Testing

Development testing of components and individual subsystems of the ECLSS will be performed at the respective subcontractor's facilities; development and qualification of the integrated ECLSS should be accomplished at the prime contractor's facility.

The test article will consist of a full-scale flight type crew and passenger compartment that will be tested at atmospheric pressure.

Building 290 of the NASA Downey facility was used for assembly and checkout of the Apollo CSM, and is well suited for testing of the crew and passenger compartment and life support systems (Figure 2-50). This building will be able to support the orbiter program plus CSM follow-on activity.

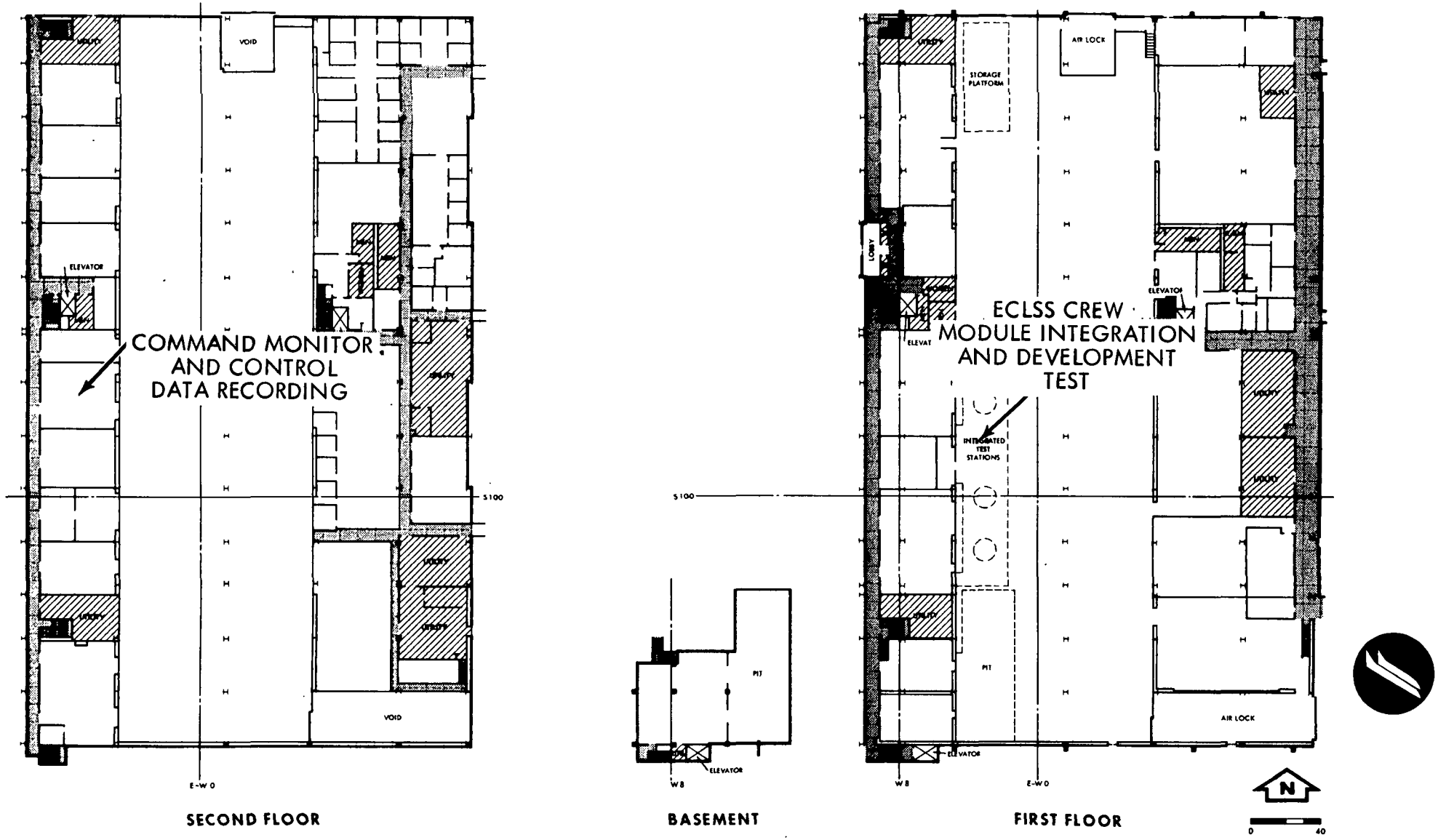


Figure 2-50. Assembly and Checkout, Building 290

Building 290 contains all basic facilities required for ECLSS testing, including a 340,000 level clean room environment. It is temperature and humidity controlled (67 ±5 F and 50 percent humidity ±5 percent). Two 15-ton bridge cranes (with 58-foot lift) cover the high bay area, and a 10-ton crane covers the low bay and air locks. The high bay area is 62 feet wide, 410 feet long, and 63 feet high. The low bay area is 49 feet wide, 410 feet long, and 43 feet high. Computer rooms within the facility provide for data acquisition, command, monitor and control of test activity. Fluid systems include LN_2, GN_2, GHe, GH_2, breathing air, water glycol, alcohol, argon, O_2, CO_2, and normal building fluid systems. Other unique building features include hazardous waste disposal, dry nitrogen, plant air system, high quality grounding, airlocks, grid trenching system, and an extensive intercom system.

Other special equipment, such as ground cooling carts for simulation of the space radiators interface with the crew and passenger compartment and heating and cooling coils and controls to simulate exterior walls, will be provided as portable equipment. The large data acquisition and control equipment utilized on Apollo systems integration testing is adaptable, with minor interface modifications required. Support laboratories exist as part of the Downey complex for analysis and verification of ECLSS components.

No basic building modifications are required to support the activity. Support equipment for the orbiter must be installed and new interfaces developed for the data acquisition and control systems. Figure 2-42 is a composite schedule of facilities for development testing.

2.3.7. Thermal Protection System Testing

Design/development testing in verification and qualification of TPS elements and components is in process during the Phase B Study contract and will be continued in Phase C effort. This work is currently being performed at the NR engineering laboratories, at the NASA MSC facility, and by others.

Facilities exist at Downey for continuation of this effort during following phases of development of the complete TPS. Efforts will be supplemented by use of the MSC 10 megawatt arc tunnel.

For verification of larger TPS structural assemblies, such as nose section or wing leading edge, the use of the 50 megawatt electrogas dynamics facility at Wright Patterson Air Force Base is planned. Also under consideration is the use of the Ames Research Center where a 60-megawatt arc facility is being planned to permit long-duration, high-velocity/high-temperature gas flow for development and extension of thermal protection technology.

Facilities capabilities exist at Downey and within the government-industrial base for the development of TPS utilizing the current concepts of panel design.

Joint use, non-interference utilization of the government facilities will be determined at the appropriate time.

2.3.8 Hydraulic System Testing

Development and qualification of components will be conducted at the facilities of the respective subcontractors.

Major development testing of the hydraulic system should be performed at the prime contractor's development laboratories. A full-scale mockup of the hydraulic system duplicating the system configuration on the vehicle as nearly as possible will be required. It is desired that the hydraulics test article be located near the avionics systems integration laboratories for future integration of guidance, navigation and control, and displays and controls subsystems with the hydraulics system.

The requirements for a full scale duplication of hydraulics system would require a room approximately 200 by 150 by 80 feet, but Engineering has indicated that a "folded" system can be utilized without degradation of the test. Full integration of the hydraulics system with the avionics system requires use of an analog-digital computer complex. Close proximity between these two laboratory areas is required for satisfactory signal-to-noise ratio between the analogs and hydraulic simulator.

NR's Building 4, Downey, satisfies the requirements of the hydraulics and controls laboratory utilizing a "folded" hydraulics mockup. Special power will be provided by installation of individual power generation units for 28 vdc and 120-volt, 400-cycle current. The area is adjacent to the main computer complex, the flight simulation laboratory and other areas to be utilized in development of the avionics subsystems. This proximity will permit integration of the GN&C and the DCM avionics subsystems with the hydraulic subsystem for flight simulation at a later phase in the development program. (See Flight Technology, Human Factors, Section 2.3.9).

A separate control room, insulated against noise of the hydraulic system, will be provided as a new installation. The hydraulic pumps with facility-type vari-drive motors will be located outside the building.

GN_2 to provide penumatics for the hydraulic system development will be provided by portable bottle dollies hooked to a facility pressure regulation and manifold station for interface with support equipment.

General-purpose equipment available includes data acquisition and communications equipment. A computer to control loads and test sequencing is to be provided as well as hydraulic service unit and workstands (Figure 2-51).

Support by the existing hydraulics laboratory will be required and utilized for the analysis and verification of malfunctioning components.

2.3.9 Flight Technology

Wind Tunnel Tests

Wind tunnel testing completed and in process during Phase B is being accomplished at various facilities within the industrial and government base. During Phases C and D, similar utilization of facilities is planned. Major wind tunnel testing to demonstrate compliance with design criteria and to evaluate configuration changes will be performed at Langley Research Center, Ames Research Center, AEDC Von Karman Gas Dynamics Facility, and NR Los Angeles Division.

Present test planning indicates that facility requirements can be met by use of existing government and industrial base wind tunnel facilities.

Arrangements for noninterference joint usage of the government-owned wind tunnel facilities will be made to provide continuity and support of the Phase C and D design effort.

Thermal Control System (TCS)

Many equipment components of the orbiter subsystems must be maintained within close temperature tolerances for operational reliability. The design of the elements that provide thermal control is strongly dependent on analytical heat transfer predictions, and must be verified by ground testing under simulated environmental conditions of temperature and pressure. As design progresses, these tests will be extended to full scale subsystems tested in thermal vacuum chambers and ultimately to qualification of the TCS by carrying out all phases of the mission: launch, orbit, and reentry.

During the design development phase of the program, extensive testing in support of this effort will be accomplished at NASA's environmental laboratory in Building 288, Downey. A number of thermal vacuum chambers and other specialized equipment exists as described in Section 3.0.

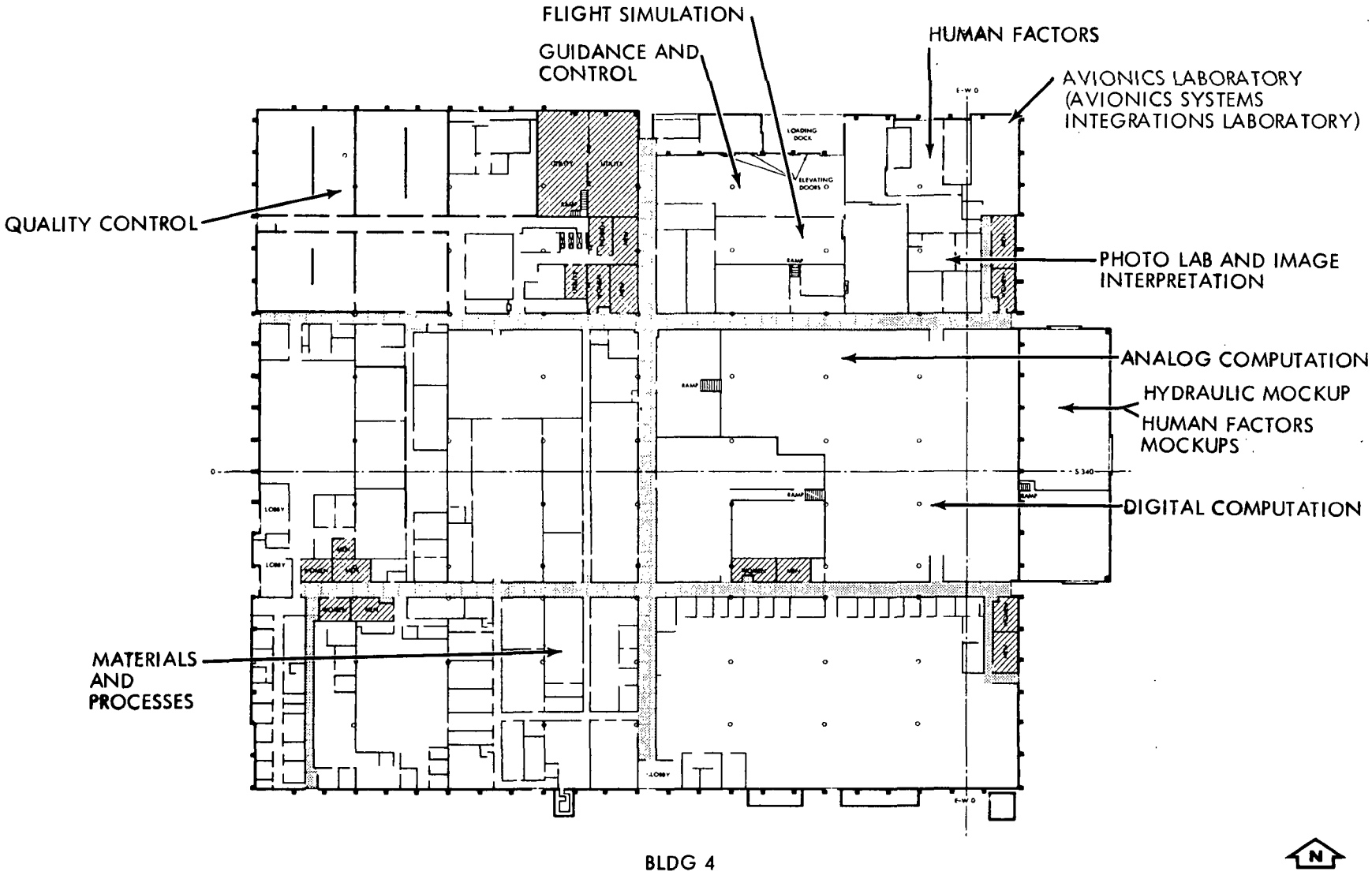


Figure 2-51. Downey Data Facilities, Building 4

A major test for verification of thermal interactions between subsystems will be performed on large sections of the fuselage using the space environmental simulation chambers at MSC, Houston.

Specific definition and configuration of the test articles have not yet been made; however, four basic sections have been identified as follows:

1. Nose gear compartment
2. Main landing gear compartment
3. Mail LO_2 tank/turbo fan engine compartment
4. OMS tank area.

These sections will be equipped with components and partial subsystems (insulation, hydraulics, electronics, heaters) that would affect or be affected by the thermal control system. It is planned that these test articles will be sized for testing by the existing MSC chambers.

Transportation of the test articles can be by barge or Super Guppy, dependent upon the ultimate size of the test specimens.

Other tests involving certification of the thermal control system, consisting of ground purge temperature conditioning and venting, will be accomplished with prime facilities at the final assembly, horizontal flight test, and launch operations sites.

Human Factors

The primary objective of this effort is to develop and evaluate design concepts and configurations affecting habitability, maintainability, operability, and efficient utilization of the orbiter. A number of mockup models and simulators will be used for optimization and integration of the man-machine relationship.

Requirements of the Preliminary Test Plan permit use of many existing facilities, certain projected activities requiring new facilities.

Flight simulation facilities will be used including the NASA Neutral Buoyancy Facility, Huntsville. The facility would be used for studies and tests relative to neutral buoyancy and tractionless environments.

The tests apply to crew operational procedures development and analysis, time line evaluation and ergometric experiments.

Modifications must be made to NR Building 004, Downey, to meet the facility requirements in support of the human factors engineering test program. As previously mentioned, human factors will extensively utilize those equipments and facilities provided within the flight simulation area (simulators, mockups, analog and digital computers, visual displays, electronic bench fabrication, and TV systems). Other areas must be modified to support the test activity. The lighting mockup requires a light-tight room with special interior treatment for non-reflectance. High intensity lights for sun shafting, control consoles, and mockup interface equipment are required.

Facilities within Building 004 must be established for a biomedical laboratory area. Test subject conditioning requires the installation of exercise, and physiological measurement equipment as well as a test data reduction area. The Division's industrial medical facilities located in this building will be modified to accommodate these requirements.

Flight Simulation

The flight simulation laboratory, Downey, initially developed to support the Apollo Program, has been expanded into a general purpose simulation laboratory and will continue to provide functional simulation support to the Shuttle Program. This support includes hybrid computation (analog plus digital), special purpose simulation equipment, and interface systems necessary for the test and development effort. The capability is organized to provide simulation support throughout the complete engineering cycle from system or vehicle conceptual stage to and through the operational phases (Figure 2-52).

Manned or unmanned vehicles or systems can be simulated in the laboratory with emphasis either on a given subsystem or on a given flight phase or mission. The simulations are closed-loop, hybrid, fixed base for man-in-the-loop studies, generally real time solutions, and have provisions for the introduction of prototype hardware into the simulation when required. Subsystems simulations include guidance and control, body dynamics, man machine integration, consumables accounting and/or management, and propulsion systems. Flight phase efforts include simulations of entry, boost, aborts, landing, rendezvous, docking, separation, interceptions, and navigation. Solving the N-body problems coupled with non-real time trajectory updating interspersed with real-time segments makes mission simulation possible.

Facility equipment capability consists of the following simulation entities:

Computer	Description
Analog	1500 operational amplifier (EAI 231R) (NR -owned)
Digital logic consoles	(HYDAC) 2 sections (NR -owned)
Digital	(2) SDS 9300's - (64K Memory, 64 A/D-D/A converters, priority interrupts, etc.) (Government-owned)

The simulation laboratory equipment includes an NR-owned general purpose crew cabin, presently being modified to shuttle craft configuration. Shuttle craft simulator and hydraulic mockup are to be added to the area. The hardware and interface equipment are both Government- and NR-owned.

For visual simulation the laboratory inventory includes a Government-owned six-foot earth globe simulator, and a four-foot lunar sphere simulator. NR-owned simulation equipment includes a two-foot celestial sphere simulator, three-degree-of-freedom target gimbal rendezvous vehicle simulator, and landing simulation capability.

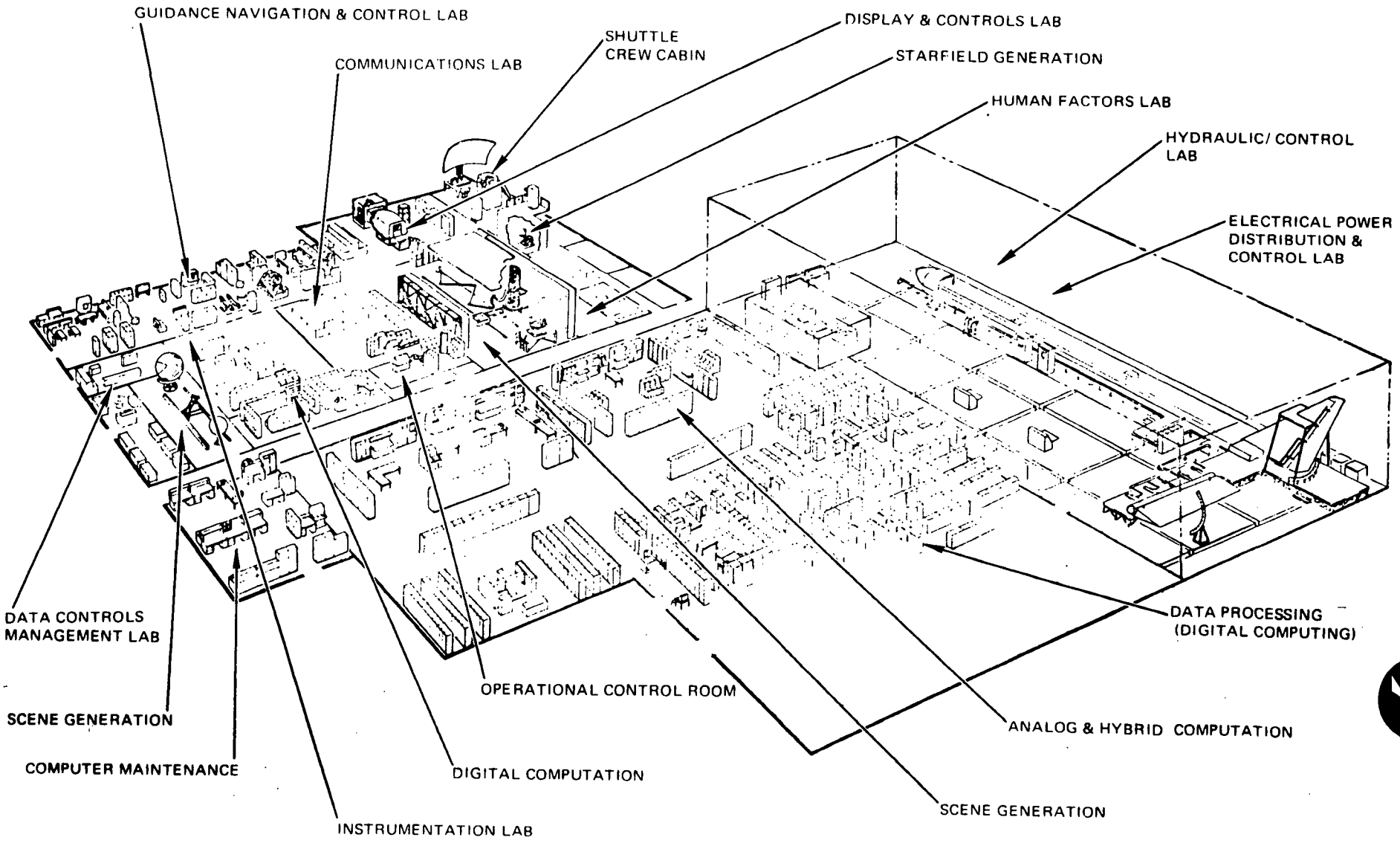


Figure 2-52. Avionics and Flight Simulation Laboratory

All facilities and equipment listed above are available on a non-interference basis to support the shuttle effort. The government-owned equipment was acquired in support of Apollo.

At Downey the existing computer center, flight simulation laboratory and guidance and navigation laboratory constitute a major capability and a sizeable investment by NASA and NR dicrectly applicable to test plans related to the avionics subsystem integration laboratory, human factors laboratory and the hydraulics and controls laboratory. Moderate augmentation of existing facilities will fulfill shuttle requirements.

Areas will also be established for garment assembly, test subject dressing, controlled environment work room, and maintenance type repair.

2.3.10 Other Subsystems Testing

Landing Subsystem

The landing subsystem consists of three major units: main landing gear, nose landing gear, and a deceleration parachute.

Development and qualification of the nose and main landing gears will be performed at the facilities of the manufacturer or at the specialized landing gear test facility at Wright-Patterson Air Force Base. Full qualification and integration of the complete landing gear and drag chute subsystems will be performed at the flight test facility on the first orbiter vehicle. Drag chute development testing will be conducted at the DOD test range, El Centro, California.

Landing gear functional tests to verify position, clearance, maintenance, and endurance of such related structures and mechanisms as doors, latches, and actuators will utilize a landing gear simulator (working mock-up) for verification and demonstration.

Due to the highly specialized nature of the equipment utilized in the full range of testing required for qualification of the landing gear, it is desirable that this effort be accomplished directly by the manufacturer. In the event that the manufacturer's facilities do not meet the full spectrum of test requirements, the specialized landing gear test facility at Wright-Patterson Air Force Base could be used to augment the manufacturer's tests or perform the entire test program.

Because of the nature of the functional tests to be conducted on the working mock-ups, these tests should logically be conducted in the prime contractor's structural laboratories where hydraulic servo-controlled systems and data acquisition equipment are available to support these tests.

NASA's structural test laboratory in Building 288, Downey, will be utilized for these tests. It has the hydraulics systems and controls plus the necessary data acquisition equipment. Size of the mockup can be accommodated in one of the low bay areas.

Docking and Payload Deployment and Retrieval Subsystem

Development test for docking and payload deployment and retrieval tests will be conducted with working mockups and breadboard devices to evaluate design concepts of the major mechanical assemblies and systems. Flight hardware will be utilized for complete subsystem qualification and interface tests.

The development test area requires an open shop environment with common utility provisioning. A bay height of 20 feet is required for the development tests area.

The qualification testing area requires that structural testing capabilities be provided to verify functional and structural integrity of system elements. Structural testing equipment including pressure control units, hydraulic struts and pumps, and a data acquisition system are also required for structural verification. Other testing activities include environmental testing of sealants and lubricants, fracture mechanics, physical and mechanical properties tests and environmental testing.

The low bay laboratory area (zones) within Building 001, Downey, provides the necessary environment for development testing of the subsystems. Mockups and mechanical systems can be easily accommodated with adequate fabrication and work area adjacent to the laboratory.

The main structural test facility within Building 288, Downey, provides 10,000 square feet of structural test floor. The facility provides four test columns 24 feet high, hydraulic proportioning units, and instrumentation devices adequate to support the qualification and interface test of the subsystems. The facility is located within the main laboratory building at Downey which provides the necessary interfaces to other supporting laboratories.

The facilities listed above are available and adequate for subject test. Modifications to facilities are not required for subject testing. It is therefore recommended that Building 001 be used for development testing and that the structural test area of Building 288 be used for qualification and interface testing of the docking and payload deployment and retrieval systems.

Crew Escape System

Ejection seats will be used in place of operational flight crew seats for the flight test vehicles. Plans are to utilize an existing, qualified system, upgraded to orbiter requirements. Development and qualification testing will be concerned with the integration of this hardware with orbiter sybsystems and the verification of their functional performance.

Full scale dynamic testing of the integrated crew escape system will be conducted using a rail sled to attain equivalent flight velocities. Final demonstration/acceptance testing will be accomplished utilizing an airborne test bed.

A working mockup of the crew compartment, which contains the systems supporting seat ejection, will be used for these tests.

Established government-owned facilities have full capabilities for supporting all phases of testing described previously. China Lake Naval Air Station (California) has a static test tower that could be utilized for simulation ejections from a vertical vehicle at the launch pad. China Lake Naval Air Station and Holloman Air Force Base (New Mexico) have high speed track test facilities and all support equipment and services for a full scale dynamic testing of the escape systems. The joint DOD Test Range at El Centro, California, has an in-flight test range including airborne test beds such as F-106B chase planes and other tracking, recording, and other support equipment and services to perform altitude eject tests.

Holloman AFB provides more extensive facilities which are currently operational on similiar programs and are recommended for the test site.

2.3.11 Component and Subassembly Testing

The development of elements and components leading to design verification, the evaluation of special materials and processes, and the qualification of whole subsystems requires extensive engineering and test laboratory capabilities at the prime contractor's central engineering base.

The prime contractor must have major facilities and equipment for environmental testing (including high and low temperature, plasmas, radiant heat, climatics, space simulation, vibration, shock and acoustics), mechanical and fluid systems (including structures, cryogenics, pneumatics, ordnance, hydraulics, mechanical systems, and environmental systems), and systems tests and development (including telecommunications, electrical power, electromagnetic compatibility, and instrumentation).

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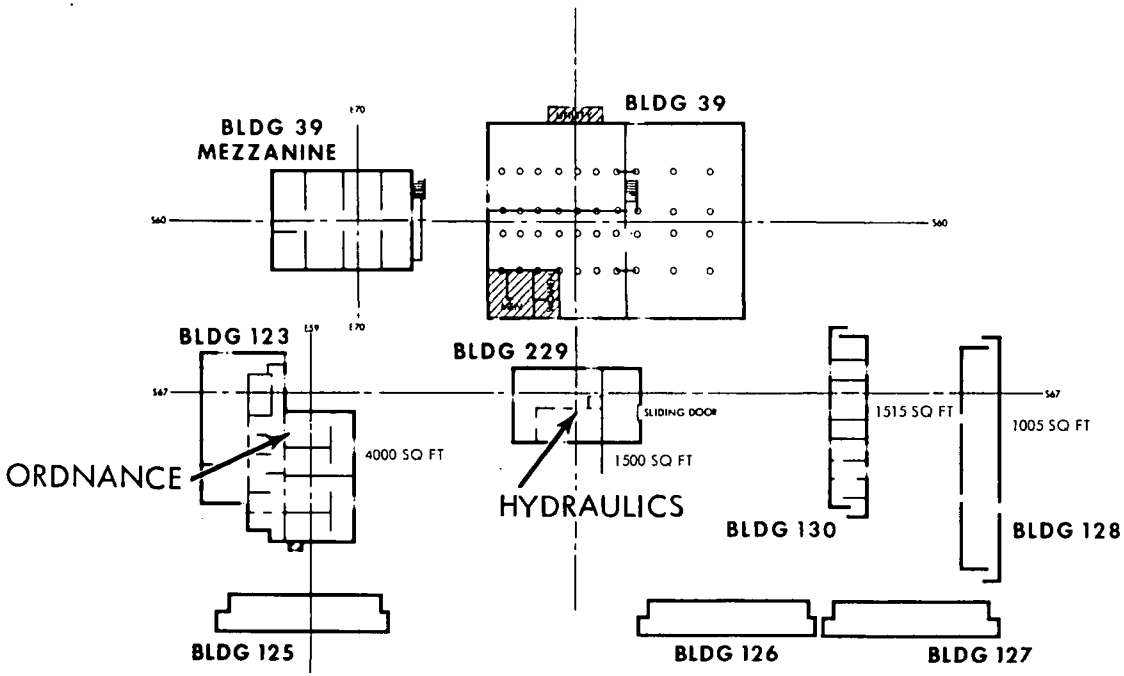


Figure 2-53. NASA and NR Laboratory and Test Facilities, Downey

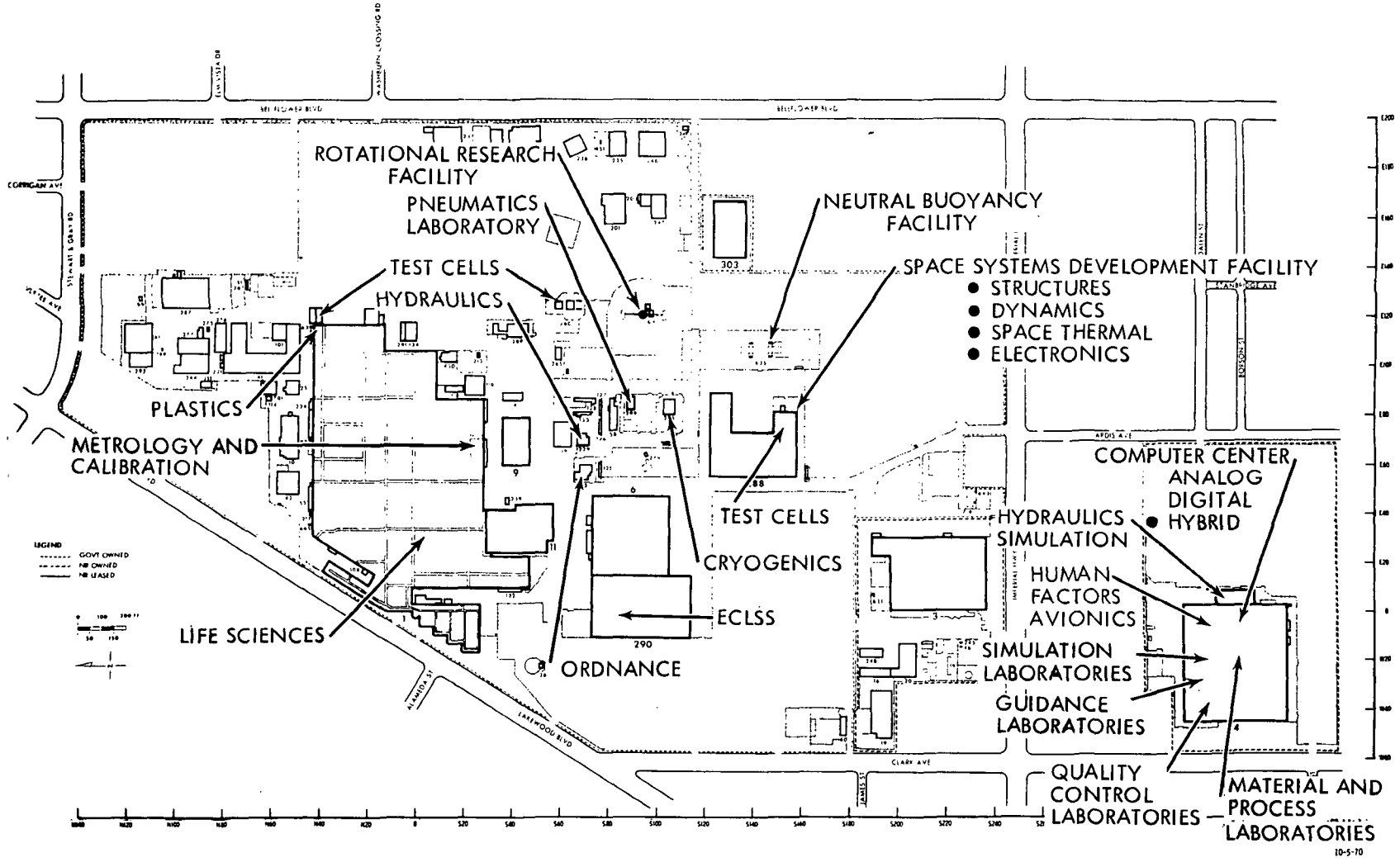


Figure 2-54. Downey Test Complex

Table 2-12. Major Facilities Required for Development Testing

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
ACOUSTICAL AND ENVIRONMENTAL TESTING – HOUSTON			
Spacecraft acoustics laboratory. NASA-MSC. Assumed available	60-ft-by-90-ft 75-ton fixed hoist 170 dB sound levels (See Page 11-1 of NASA Technical Facilities Catalog for details.)	No modifications required.	Existing satisfactory
FLIGHT TECHNOLOGY AND THERMAL CONTROL SYSTEM TESTING – HOUSTON			
Verification testing of large composite section of fuselage with partial systems installed. MSC space chamber test facility.	Thermal vacuum chamber A.	None anticipated.	Existing satisfactory.
LANDING SUBSYSTEM			
Wright Patterson AFB USAF Available	Landing gear facility	No modification required.	Existing satisfactory.
El Centro DOD Range DOD Available	Drag chute development	No modifications required.	Existing satisfactory.

Table 2-12. Major Facilities Required for Development Testing (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
STRUCTURAL TEST, MAJOR TEST ARTICLES – HUNTSVILLE			
Building 4619 NASA Assumed available	Structural test floor with 500K anchor points, two 20-ton bridge cranes, 80-ft hook height.	Existing.	Existing available.
	Hydraulic load maintainers.	Existing.	
	Hydraulic power dist. syst.	Existing.	
	Ignition heat units and controllers.	New required.	
	Control room.	Existing.	
	Data acquisition.	Existing.	
	Instrumentation and controls.	Additional required.	
PNEUMOSTATIC CREW-MODULE TESTING – DOWNEY			
Building 260 test laboratory. NASA. Available.	25-ft-by-25-ft-by-25-ft test cell.	Modify - add 10 feet to height. Relocate sliding hatch. Modify platforms.	Existing satisfactory.
	Control room.	Adequate.	
	Data acquisition.	Existing adequate.	
	Pressurization system.	Existing adequate.	
	Instrumentation and controls.	Existing adequate.	
	Facilities utilities and support.	Existing adequate.	
	Handling equipment stick cranes, 25-ton, 50-ft boom.	Existing. $50,000 (ROM est)	

Table 2-12. *Major Facilities Required for Development Testing (Cont)*

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
AIR-BREATHING ENGINE PROPULSION SYSTEM TESTING – SANTA SUSANA			
WSTF Test Stand 402 NASA Available.	Jet engine thrust stand with exhaust diffuser and thrust measurement. Control center. JP4 storage and distribution. General purpose data acquisition. Facilities utilities and support. Gantry Crane - 20-ton.	Modification $100,000 (ROM est). Existing adequate. Use test article tanks. Existing adequate. Existing adequate. Existing adequate.	Existing satisfactory.
MAIN PROPULSION TANKS CRYOGENIC - SEAL BEACH			
Cryogenic-hydrostatic test facility.	500 ft-by-500 ft hard stand with access roads. LN_2 storage and distribution, 60,000 gallon Static test tower 25-ton derrick with 100-foot boom, 250-foot hoist height. Retention dikes with security fence.	 Add LN_2 storage and distribution. Modify existing test tower. Use mobile crane. ROM $1,500,000.	As noted.

Table 2-12. Major Facilities Required for Development Testing (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
	Control center. Data acquisition. Instrumentation and controls. Transportation.		
MAIN PROPULSION CLUSTER FIRING TESTING – KSC			
LC-39A. NASA.	Static firing hard stand.	Flame deflection - modify to "wet". Firex modifications and water deluge and other major modifications. $4,000,000.	Existing satisfactory.
	Control center. Other supporting technical facilities. Propellants. Pressurants. Data acquisition. Firex. Test controls. Instrumentation (operational and special cluster firing).		

Table 2-12. Major Facilities Required for Development Testing (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
ORBIT MANEUVERS AND ATTITUDE CONTROL PROPULSION SYSTEM TESTING			
Test Area 400	200,000 ft^2.		Existing satisfactory.
WSTF, NASA	9,500 ft^2 under roof.		
Available.	Central control center.	Minor modifications.	
	4 test modules.		
	3 test stands.		
	Altitude simulation.	Existing.	
	LO_2 storage dewars.	Distribution system required.	
	LH_2, various dewars.	Relocate existing dewars.	
	LN_2	Existing.	
	General purpose data acquisition equipment.	Minor modifications or additions.	
	Facility utilities instrumentation controls	Existing adequate. ROM $1,000,000.	

Table 2-12. Major Facilities Required for Development Testing (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
THERMAL PROTECTION SYSTEM TESTING – HOUSTON			
MSC-ARC jet facility. NASA. Available.	10 megawatt arc tunnel (for design evaluation verification of TPS components).	No modifications required.	Existing satisfactory.
THERMAL PROTECTION SYSTEM TESTING – WRIGHT PATTERSON AFB			
Air Force Flight Dynamics Laboratory (AFFDL). USAF. Assume available.	50 megawatt electrogasdynamics facility (for verification of composite sections of leading edge of wing, nose, etc.).	None anticipated.	Existing satisfactory.
HUMAN FACTORS FLIGHT TECHNOLOGY TESTING			
Joint DOD test range. Assume available.	Inflight test range. Airborne test beds (F-106B or equivalent). Chase planes with high-speed photographic capability. Ground-based data acquisition.	No modification required.	Existing satisfactory.

Table 2-12. Major Facilities Required for Development Testing (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
WIND TUNNEL TESTING – VARIOUS LOCATIONS			
Wind tunnels. Langley Research Center. Ames Research Center. Arnold Engineering Development Center. Los Angeles Division, NR.	Various wind tunnels existing, Government/ industrial capability	No modifications required.	Existing satisfactory.
ESCAPE SYSTEMS TESTING – HOLLOMAN AFB, NEW MEXICO			
Holloman AFB Available	Static firing test tower. High speed track test facility (sled).	No modifications required. No modifications required.	Existing satisfactory.
ELECTRICAL AND HYDRAULICS POWER SYSTEMS TESTING			
WSTF Test Stand 302, NASA Available.	Test Stand 302 Control center. LH_2 portable dewars. LO_2 portable dewars. GN He at 5000 psi. General purposes data acquisition. Controls and instrumentation. Facilities utilities and support.	ROM $75,000. No major modifications required. Required. Existing Existing adequate. Minor requirement assumed. Existing adequate.	Existing satisfactory.

Table 2-12. Major Facilities Required for Development Testing (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
STRUCTURAL – ENVIRONMENTAL DEVELOPMENT TESTING			
Building 288. NASA. Available.	80,000 ft^2 structural and environmental test laboratory with structural test floor 75,000-lb. anchor points; 2 5-ton overhead bridge cranes.	None required.	Existing satisfactory.
ACOUSTICAL TESTING – NR LOS ANGELES DIVISION AND EL SEGUNDO			
Acoustical test facility. NR. Available.	Acoustical Test Chamber 15 ft-by-15 ft-by-14 ft with random, sinusoidal, high pressure level capacity up to 170 dB.	None required.	Existing satisfactory.
ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEMS DEVELOPMENT TESTING			
Building 290. NASA. Available.	Perform verification testing of crew module and life support systems.	Minor modifications.	Existing satisfactory.

Table 2-12. Major Facilities Required for Development Testing (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
HYDRAULIC, AVIONICS, FLIGHT SIMULATION, AND HUMAN FACTORS DEVELOPMENT TESTING – DOWNEY			
Building 004. NR. Available.	Laboratory areas for the following development test functions: Hydraulics Controls Lab Avionics systems laboratories Human factors laboratories. Flight simulation laboratories and computer support Data ground station.	Basic brick and mortar facilities adequate. Rearrangement, relocation and establishment of new laboratories required.	Existing satisfactory.

2.4 HORIZONTAL FLIGHT TEST FACILITIES

2.4.1 Test Requirements

The horizontal flight test program will be accomplished primarily with the first orbiter vehicle. It will be conducted over a period of approximately three years at a government site equipped for Category I flight testing. The first phase, to be completed prior to mated flight, will require about eighteen months and will involve approximately 180 hours of flight time. See Preliminary Test Plan (SD 71-105-2).

2.4.2 Site Evaluation Considerations

Ninety-four sites were considered for horizontal flight testing. A number of these were included solely because of their potential dual usage for both flight testing and launch operations. These, however, were eliminated as a result of the operations site studies. Three sites were selected from the original list for evaluation as flight test sites. Table 2-13 is a comparison of these sites.

In addition to the evaluation factors listed in Table 2-13, flight test program safety, proximity of alternative landing sites, and prevailing weather conditions were regarded as essential considerations. Location of the final assembly facility and launch operations site also influenced flight test site selection in view of ferry and transportation requirements.

The three sites best qualified from a flight test capability and location standpoint are Edwards Air Force Base, Eglin Air Force Base, and KSC.

2.4.3 NASA Flight Research Center, Edwards Air Force Base

Use of the NASA Flight Research Center at Edwards Air Force Base for flight testing would require minor modifications to meet shuttle facilities criteria. The primary modification would be the addition of a safing area to conduct fueling, engine run up, verification and checkout of the power generation system, and purging of the LO_2 and LH_2 tanks. This area would be remotely located on a concrete pad adjacent to a taxi strip to meet the safety requirements stemming from the quantities of LO_2 and LH_2 used in the power generation system.

The existing M&M (Building 1600) or C-5A Hangar (Building 1623) would be utilized for maintenance, modifications, and repair. Approximately 75,000 square feet would be required to provide accommodations for two

Table 2-13. Horizontal Flight Test Site Comparison

Facility Item Consideration	Shuttle (Orbiter) Requirements	Candidate Site Capabilities and Limitations		
		NASA FRC, Edwards AFB	Eglin AFB	KSC
Hangar	75,000-ft^2 minimum area 80-ft chord height.	M&M and C-5A hangar adequate	King hangar requires modification	Adequate*
Runway	10,000 ft long, 300 ft wide.	15,000 ft (superior)	12,000 ft	10,000 ft
Track range data acquisition	Suitable for Category I test and development.	CENTCON, existing FRC mission control	Eglin Gulf Test Range	Eastern Test Range
Support shops	Sheet metal, machine, jet engine, avionics, electronics, standards and calibration, tubing and fluids.	Use existing shops	Augment flight instrument calibration	Use existing shops
Landing and navigation aids.	Existing	Existing	Existing	Existing*
Weather	Maximum number of clear days, minimum precipitation and lightning storms	Least constraint	Some constraint	Some constraint
Alternative landing sites	Maximum number of possible landing sites around flight range	9 dry lakes and 3 airfields	2 within 75 miles	3 within 50 miles

*Based on early provision as operations site.

orbiters (the maximum number undergoing flight testing during same period). Portable work platforms would be used within the hangar and at the safing area. The existing weight and balance facility and the engine thrust-calibration facilities would be utilized without modifications. Base support shops and services would be required throughout the flight test program (Figure 2-55).

Since the recommended final assembly facility is not adjacent to the flight test site, an intermediate airfield would be used for preflight testing. With Seal Beach used for final assembly, the Naval Air Station at Point Mugu, California, would serve this purpose. The completed orbiter would be transported from Seal Beach to Point Mugu by barge (Figure 2-14).

The facility at Point Mugu (Figure 2-56) meets the requirements for the planned preliminary tests, including taxi, braking, and engine run-up tests, as well as ground testing and checkout of the vehicle systems. The runway is 11,000 feet long and has an unimpaired takeoff area over the ocean. San Nicholas Island and Vandenberg AFB, California, provide alternative landing sites. Other capabilities are available at the Pacific Missile Range to support the orbiter including: aircraft support shops, operations control, flight tracking and data acquisition, fueling facilities, instrumentation calibration, offices, shop work area, storage and warehousing, and special technical services.

Initial testing would be accomplished in a remote area on the apron of the runway. This area also would be used for fueling and preflight functions. A dock, ramp, and roadway to the south side of the main runway would be required for transportation of the orbiter from the barge.

2.4.4 Eglin Air Force Base

Eglin Air Force Base would be a candidate with final assembly at Michoud, Louisiana, or Tulsa, Oklahoma. The completed orbiter would be transported from Michoud by barge to Eglin Air Force Base, as no accessible airfield exists at Michoud. With Tulsa as the final assembly site, the completed orbiter could be ferried to Eglin Air Force Base after preliminary flight testing at the adjoining Tulsa Municipal Airport. With Seal Beach used for final assembly, additional program cost would be imposed by utilization of intermediate ferry sites or ocean transport to Eglin.

Eglin Air Force Base would require modifications to the King Hangar or use of the climatic hangar for refurbishment, maintenance, and repairs requiring full vehicle weather protection. Nose-in use of the King Hangar could provide a compromise capability for these activities without building modifications. It would be necessary to provide a safing area at a remote location adjacent to the main runway, and access to the Gulf and docking facilities would be required.

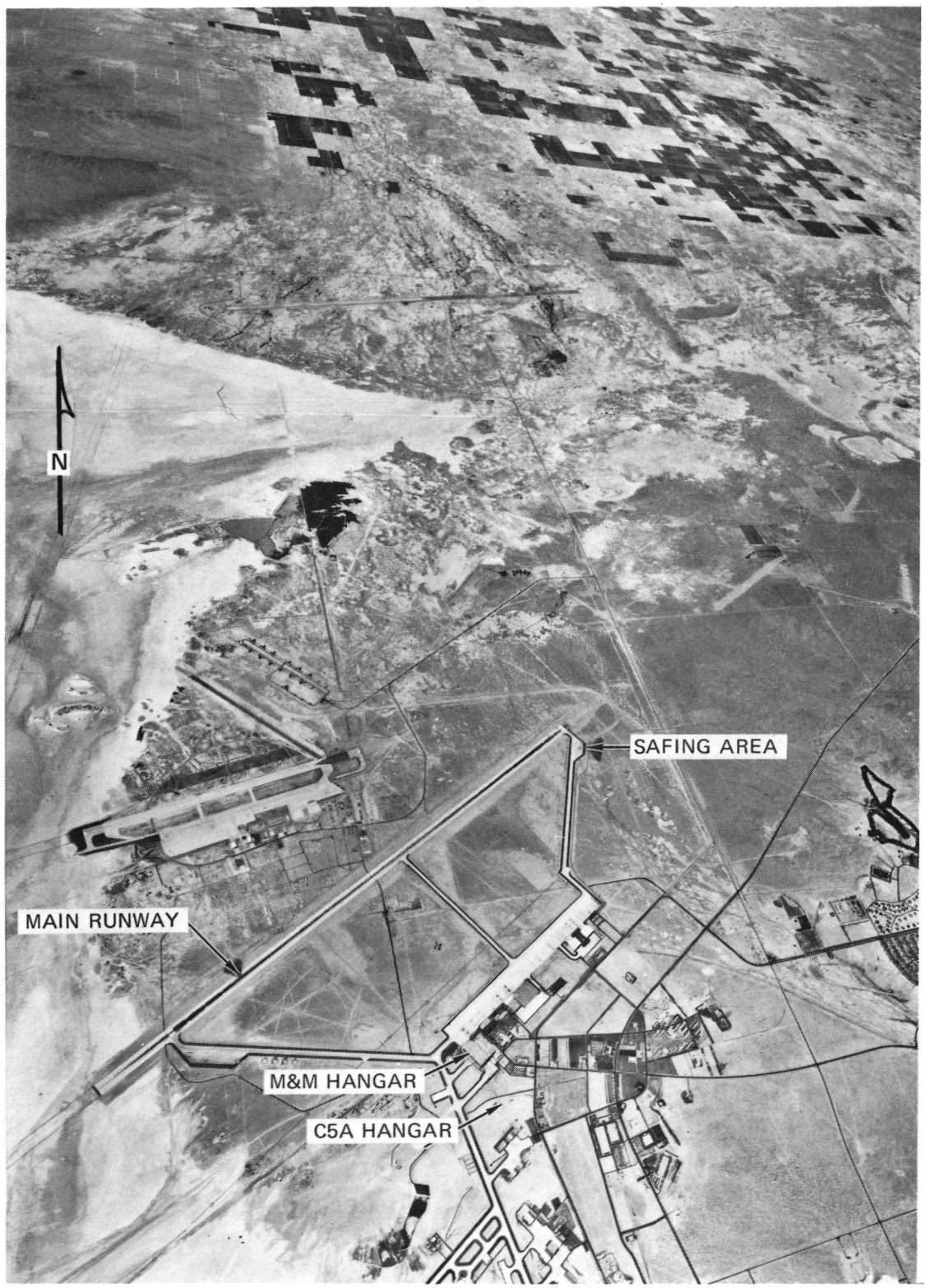


Figure 2-55. Edwards Air Force Base Runway and Safing Area

Figure 2-56. Aerial View, Point Mugu NAS

Weight and balance testing could be accomplished with portable instrumentation and equipment, but would be compromised unless full wind protection is provided. Flight instrumentation-calibration capability would require augmentation.

2.4.5 Kennedy Space Center

Selection of KSC as the launch operations site would make it a logical candidate for flight testing. All basic facility requirements would be fulfilled by early preparation and use of the operational site facilities to meet the flight test program schedule. (Technical capabilities for flight testing at any of the other candidate launch-operations sites, Holloman, Vandenberg, Clinton-Sherman, and Wendover, could be justified by the same rationale.)

The weight and balance requirements would be met with portable test equipment and instrumentation within the M&C Building. Alternative landing fields within 50 miles are McCoy Air Force Base, Cape Kennedy Skid Strip, and Patrick Air Force Base.

2.4.6 Summary and Recommendations

Horizontal flight testing can be accomplished at any of the three primary sites. Based on the analysis of the final assembly sites, which established Seal Beach as the recommended site, and the availability and capabilities of existing flight test facilities, the NASA Flight Research Center at Edwards Air Force Base is the recommended site.

Edwards Air Force Base offers the greatest flight safety because of the number of alternative landing fields and dry lakes near the flight range. The weather is satisfactory 99 percent of the days with thunderstorm and lightning occurring 0.1 percent of the time on an hourly basis. The main runway is 15,000 feet long. Rodgers Dry Lake, the primary alternative landing site, is 11 miles long. Eight other dry lake beds in the immediate area have landing areas longer than 10,000 feet, with twin-tandem loading capacity greater than 300,000 pounds. Palmdale Air Force Base, George Air Force Base, and China Lake NAS are additional alternative landing sites within 50 miles of the base.

The C-5A hangar has sufficient area available and the necessary height to accommodate the orbiter. Range tracking facilities and data acquisition equipment exceed orbiter test requirements. Adequate base support shops, services, offices, and administrative areas exist.

Ferry requirements imposed by location of the final assembly site at Tulsa, KSC, Michoud or Seal Beach are variable, but are not considered to be significant. All of the final assembly sites, except KSC, would require the use of an intermediate airfield for preliminary flight.

Program operating costs at the NASA Flight Research Center at Edwards Air Force Base are estimated to be lower due to use of an established flight test center with existing support shops and services shared by multiple-test programs.

2.4.7 Implementation of Recommended Horizontal Flight Test Site

The following basic facilities at the NASA Flight Research Center can be used without modification to support the orbiter horizontal flight test program:

1. C-5A hangar (also contains office space, shops, and warehouse)
2. Weight and balance facility (Building 1830)
3. Engine thrust stand (ABES checkout)
4. General support shops in the M&M building
5. Main runway
6. Other NASA and AF base support facilities

New construction planned includes the facilitization of a safing area to be located off the taxi strip and immediately adjacent to the west end of the main runway. This area will be used for fueling, safing, engine-run, and checkout of the auxiliary power unit and other vehicle systems. High-pressure purge gas storage, distribution, pressure regulation, control, and fuel manifold for truck fueling will be required.

Access platforms for crew access and service and a portable trailer for test personnel, SE, and data acquisition equipment will be provided. A portable ground support trailer with electrical and hydraulic power, vacuum, and ac electrical service also will be provided.

Existing facilities at the Pacific Missile Range at Point Mugu require only the addition of a dock, ramp, and roadway to satisfy the orbiter requirements to perform green flights.

Major horizontal flight test facilities are listed in Table 2-14. The overall implementation schedule for NASA Flight Research Center requires three months for design, nine months for construction, and three months for activation (Figure 2-57).

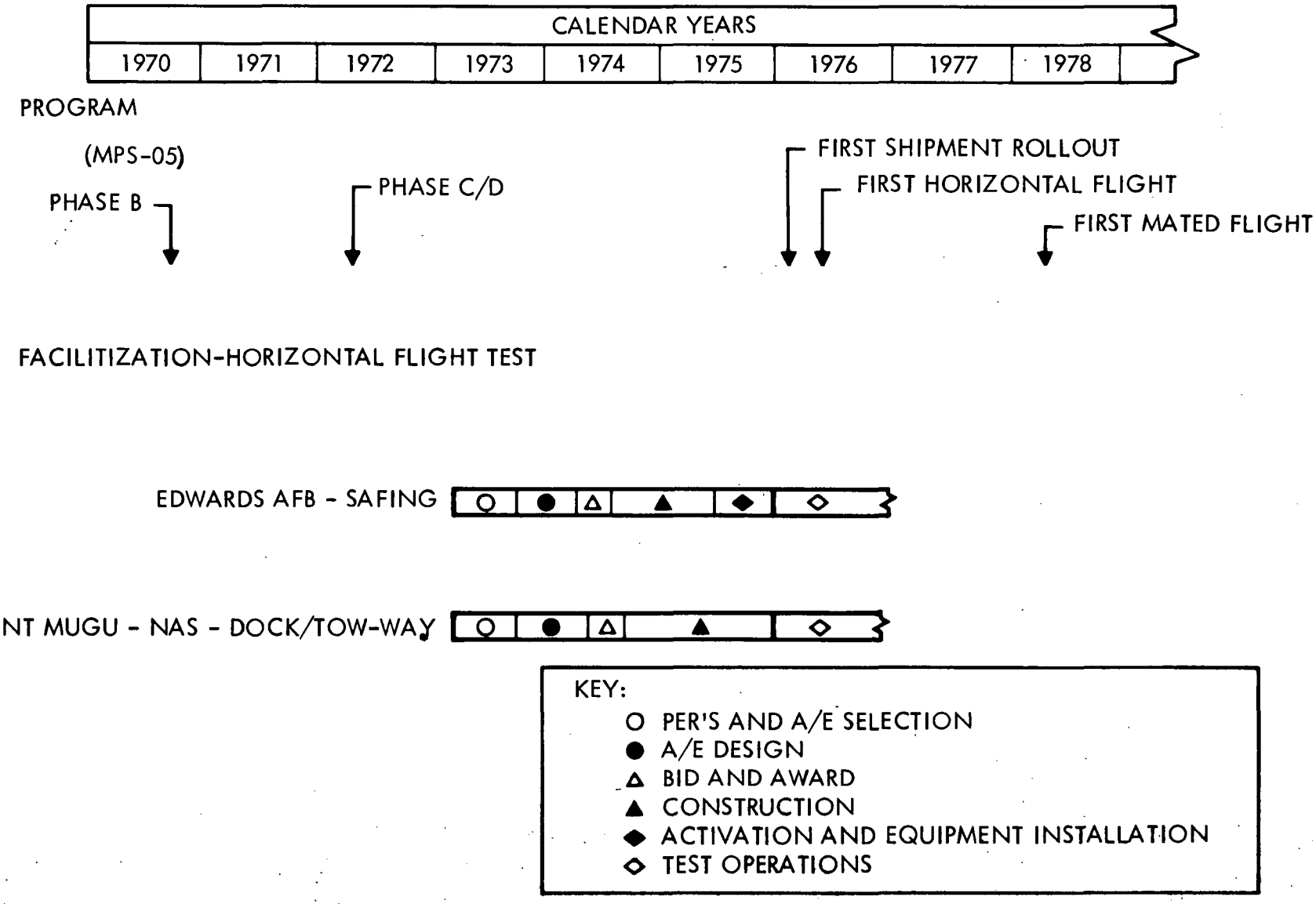


Figure 2-57. Program and Horizontal Flight Test Schedule

Table 2-14. Major Facilities Required for Horizontal Flight Testing

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
HORIZONTAL FLIGHT TESTING – EDWARDS AFB			
C-5A hangar.	270-ft-by-300-ft-by-85-ft height.	No modifications required.	Existing satisfactory.
M&M building.	Sheet metal, jet engine, electronics, flight instrumentation, avionics, tubing, etc.	No modifications required.	Existing satisfactory.
Thrust calibration facility.	Aircraft static thrust, weight loss measuring system.	No modifications required.	Existing satisfactory.
Weight and balance facility.	300-ft wide by 400-ft long by 75-ft high with 300,000-lb scale.	No modifications required.	Existing satisfactory.
Takeoff and landing facility.	15,000-ft main runway with photo theodolites.	No modifications required.	Existing satisfactory.
Flight test range.	EFTR (Vandenberg to Wendover)	No modifications required.	Existing satisfactory.
Mission control and range monitoring facility.	CENTCON (Edwards AFB, Mission Control, NASA, FRC)	No modifications required.	Existing satisfactory.
Data acquisition transmission facility.	DATS (Real-time instrumentation & communications supptg EFTR)	No modifications required.	Existing satisfactory.
Photographic facility.	Motion picture and still data acquisition services	No modifications required.	Existing satisfactory.
Computation laboratory.	Data processing, reduction, computing.	No modifications required.	Existing satisfactory.
Closed-circuit TV.	Flight test monitoring.	No modifications required.	Existing satisfactory.

Table 2-14. Major Facilities Required for Horizontal Flight Testing (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
Flight test support facility.	Chase planes, fire and rescue, towing.	No modifications required.	Existing satisfactory.
SAFING AREA – FLIGHT TEST SITE (EDWARDS AFB)			
Edwards AFB safing area. USAF. Assume available	250 ft-by-250 ft. Concrete pad with Firex system, vent stack, grounding system, lightning arrest system, fuel manifold.	New. $500,000 (ROM est).	440V 3-phase power. Water (Firex).
PREFLIGHT TESTING – POINT MUGU			
NAS Point Mugu. USN. TBD. Docking facility. USN. Assume available	Dock and tow away.	New. $750,000 (ROM est).	Portable utility service units.
TRANSPORTATION FROM SEAL BEACH TO POINT MUGU			
Transport orbiter from Seal Beach to NAS, Point Mugu. USN. USN.	Barge 240 ft long by 100 ft wide. Ocean tug.	Modification. $200,000 (ROM est).	

2.5 COMBINED BOOSTER AND ORBITER OPERATIONS FACILITIES

This section contains a facilities plan for the vertical flight test and operations phases of the Space Shuttle Program. It is based on the Operations Plan trade studies in which the following activities were considered:

1. Cargo and storable loading and unloading.

2. Booster self-ferry capability.

3. Vehicle mating, transporting, erecting, and servicing concepts.

4. Cryogenic propellant loading.

The Operations Plan is based on 445 flights over a ten-year period with a maximum of 75 flights in one year. Four boosters and five orbiters are planned.

2.5.1 Operations Requirements

Preparation for launch involves payload preparation and loading into the orbiter. The orbiter and booster vehicles are erected, mated, and transported to the launch pad; however, this sequence of events may vary at different sites, depending on the facilities employed. These considerations are discussed for each site in subsequent sections.

At the launch pad, propellants are loaded into the vehicles and into any payload that requires fueling. Crew and passengers then board the vehicles, final launch checkout and countdown are conducted, and the vehicles are launched.

Within approximately an hour and a half after launch, the booster will have separated from the orbiter, reentered the atmosphere, started its JP-fueled air-breathing engines, flown back to the launch site, and prepared for horizontal landing. Landings at fields other than the launch site are being studied, particularly for certain missions. Should the use of alternative landing sites become necessary, the booster will be refueled with JP and flown back to the launch site. The orbiter, on completion of its orbital mission, follows the same flyback plan.

As the vehicles approach the landing site, ground stations establish tracking and voice communications with the crew. An automatic landing system assists in the landing. After landing, the vehicles proceed to a safing area under their own power. At the safing area, crews, passengers, and payloads are removed; pyrotechnic devices are removed or safed; residual propellants are removed; and the tanks are purged.

The vehicles are then towed to the maintenance and checkout facility for planned inspection, maintenance, and checkout. Unplanned maintenance and repair work are also accomplished at this facility. Following checkout operations, the vehicle is ready for reuse. Should the next assigned flight be delayed, the vehicle is stored.

2.5.2 Site Evaluation Considerations

Six primary operations site candidates were studied (Figure 2-58):

1. Clinton-Sherman Auxiliary Air Force Base, Oklahoma.
2. Edwards Air Force Base, California.
3. Holloman Air Force Base, White Sands Missile Range, New Mexico.
4. Kennedy Space Center (KSC), Florida.
5. Wendover Auxiliary Air Force Base, Utah.
6. Western Test Range (WTR), California.

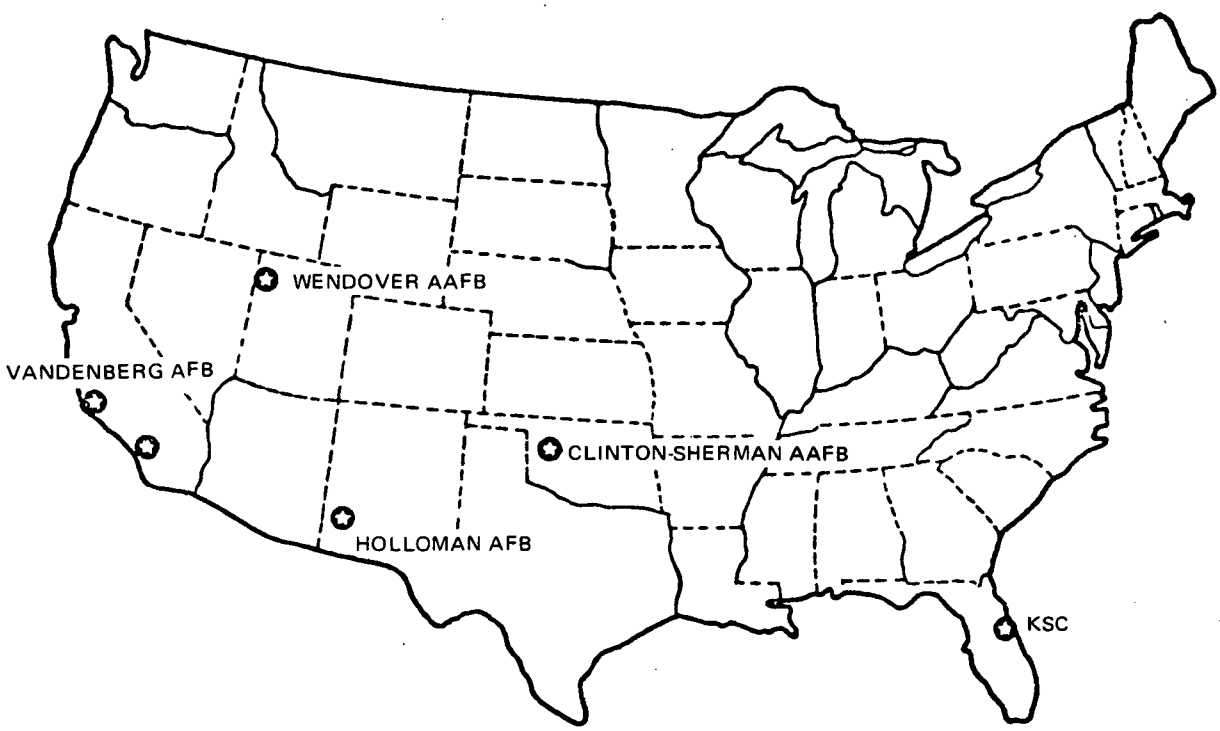
Numerous other candidate sites were eliminated from further consideration for a number of reasons, including excessive population density, inclement winters, dense commercial air traffic, payload penalties due to a combination of north latitude and low elevation, and lack of suitable base facilities.

The six prime sites were evaluated for mission operations based on the mission model, ground operations, facilities, and weather. The mission operations analysis was based on an 1,100-nautical-mile crossrange capability, varying payloads, and return of both vehicles to the launch site. All-azimuth launches were studied with emphasis on the following three primary missions:

1. 100-nautical-mile due east circular orbit.
2. 100-nautical-mile south polar circular orbit.
3. 270-nautical-mile orbit at 55 degree inclination.

Each site was analyzed with respect to the following considerations:

1. Launch site effect on vehicle sizing and payload capability.
2. Booster overflight areas.



LAUNCH SITE	ELEVATION (FT)	GEOGRAPHIC COORDINATES	
		LATITUDE	LONGITUDE
CLINTON-SHERMAN AAFB	1,923	35° 20' N	99° 12' W
EDWARDS AFB	2,302	34° 54' N	117° 52' W
HOLLOMAN AFB	4,094	32° 51' N	106° 06' W
KSC	9	28° 30' N	80° 36' W
WENDOVER AAFB	4,240	40° 43'N -	114° 02' W
WTR	368	34° 43' N	120° 34' W

Figure 2-58. Primary Operations Site Candidates

3. Alternative recovery sites.

4. Vehicle recovery after abort.

5. Hazards and environmental considerations.

6. Traffic model mission performance.

7. Peculiar vertical flight test situations.

8. Local socioeconomic considerations.

9. Site security.

Because of the varying launch orbits and the number of evaluation factors, no site rated consistently high in all categories. Each site had one or more significant detracting characteristic for some portion of the mission model, and all sites tended to rate high for certain orbit inclinations and low for others.

A separate weather analysis was made for each of the six candidate sites. U.S. Weather Bureau historical data applicable to each site over the past ten years were examined. These data included detailed records concerning wind, rain, electrical storms, temperature, humidity, snow, ice, ceiling, and visibility. The effects of these conditions on ground operations, launch operations, launch preparation, and recovery operations were evaluated. The major considerations were ceiling and visibility, wind velocity and frequency of electrical storm activity. Weather was determined to be acceptable at all six of the sites, although each exhibited some weather characteristics that could inhibit shuttle operations.

Facility requirements to support ground operations were defined and evaluated for each site. The major facility requirements are summarized as follows:

1. Payload Preparation Area. Payloads may contain as many as seven payload units and may include cryogenic propellants, storable propellants, gases, and radioactive materials. The main preparation area should contain at least 32,000 square feet and should be controlled to Class 100,000 clean conditions. A 30-ton service crane also should be available. Separate remotely-located buildings are required for hazardous propellants, pyrotechnics, and radioactive materials.

2. Erecting, Mating, and Transporting Facilities. The site must provide facilities to accomplish these tasks and place the mated vehicles on the launch pad.

3. Launch Complex. Two launch pads are required to support the planned launch rate. Each pad requires storage and loading facilities for 1.8 million gallons of LH_2, 1.2 million gallons of LO_2, and 35,000 gallons of JP fuel. Pressurant and purge gas systems as well as utility supplies are required. A launch control center with tracking, communications, range safety, and related systems must be provided.

4. Landing Facility. Returning vehicles require a FAA Category II landing facility at the operations site. The runway should be 200 feet wide, plus 50-foot-wide shoulders, and 10,000 feet long (at sea level), and capable of withstanding a booster landing weight of 650,000 pounds on twin-tandem gear. A control tower and landing, communication, and tracking systems are required.

5. Safing Facility. A safing facility is required to receive the booster and the orbiter after landing, remove crews and passengers, remove payloads, drain and dispose residual propellants, purge the tanks, remove or safe pyrotechnic devices, and prepare the vehicles for towing to the maintenance and checkout facility.

6. Maintenance and Checkout Building. Support of the planned launch rate requires two maintenance and checkout stations for the booster and two for the orbiter. Booster checkout and maintenance requires an area 220 feet wide and 640 feet long with a 120-foot clear height over the vertical stabilizer and a 70-foot clear height in the remaining area. The orbiter requires a 170-foot by 510-foot area with an 80-foot clear height.

7. Storage Facility. Storage space is required for all vehicles. The maintenance and checkout facility can store four vehicles; however, additional space is required for two boosters and three orbiters.

8. Support Activities. Included among the numerous support activities required at the operations site, are shops, laboratories, training facilities, office areas, crew and passenger quarters.

To obtain relative initial costs for the six sites, preliminary implementation plans were developed. A summary of the facilities implementation needed at each site to meet the requirements noted is given in the following subsections.

2.5.3 Clinton-Sherman Auxiliary Air Force Base

Clinton-Sherman Auxiliary Air Force Base (inactive)is a former SAC operations base located approximately 100 miles west of Oklahoma City. The base has 1.9 million square feet of permanent structures. Payload preparation

could be performed in Building 101, a 65,000-square-foot hangar with a 32-foot clear height. A 32,000-square-foot area would be converted to Class 100,000 clean conditions. Cranes would be modified to provide 30-ton lifting capacity. Existing buildings in the ordnance depot area could be converted for hazardous propellants, pyrotechnics, and radioactive materials. Utility services would have to be increased for these buildings.

At Clinton-Sherman, the orbiter would be mated to the booster horizontally in the maintenance and checkout building. Movement of the mated vehicles to the launch pad in the horizontal position would require construction of an 80-foot-wide, 4-1/2-mile-long tow way. A bascule-type erector would be constructed at each launch pad to erect the mated vehicles. Figure 2-59 is a sketch of this type of erector.

An entire, new launch complex would have to be constructed. Included are two launch pads with service towers, propellant storage and loading systems, gas storage and loading system, and new utility support. In addition, a new launch control center would have to be built, and new tracking, communication, and range safety systems would have to be installed. The recommended location for the new launch complex is west of the ordnance depot area (Figure 2-60).

The landing facility at Clinton-Sherman is adequate for the Space Shuttle operations, the runway being 300 feet wide and 13,502 feet long with 1,000-foot overruns at each end. A new safing area would be constructed at the south end of the runway.

A new 230,000-square-foot building with the noted clear heights would have to be constructed for maintenance and checkout. Existing buildings at Clinton-Sherman are limited to 60-foot bays and 32-foot clear heights. The recommended site for this building is along the east side of the runway. To accomplish horizontal mating, a 150-ton crane with a 120-foot hook height would have to be provided in one bay of the new building.

A 180,000-square-foot building would have to be constructed to store two boosters and three orbiters. It would be contiguous with the maintenance and checkout building. Substantial facility additions also would be required to provide the support functions needed for operations activities. Laboratories would have to be constructed and facilitized. Existing buildings would be converted for training, crew, and passenger quarters and support shops.

2.5.4 Edwards Air Force Base

Edwards Air Force Base is a major flight test facility located approximately 90 miles north of Los Angeles. Buildings 1207 and 1210 could be converted for payload preparation to meet the clean-room requirements.

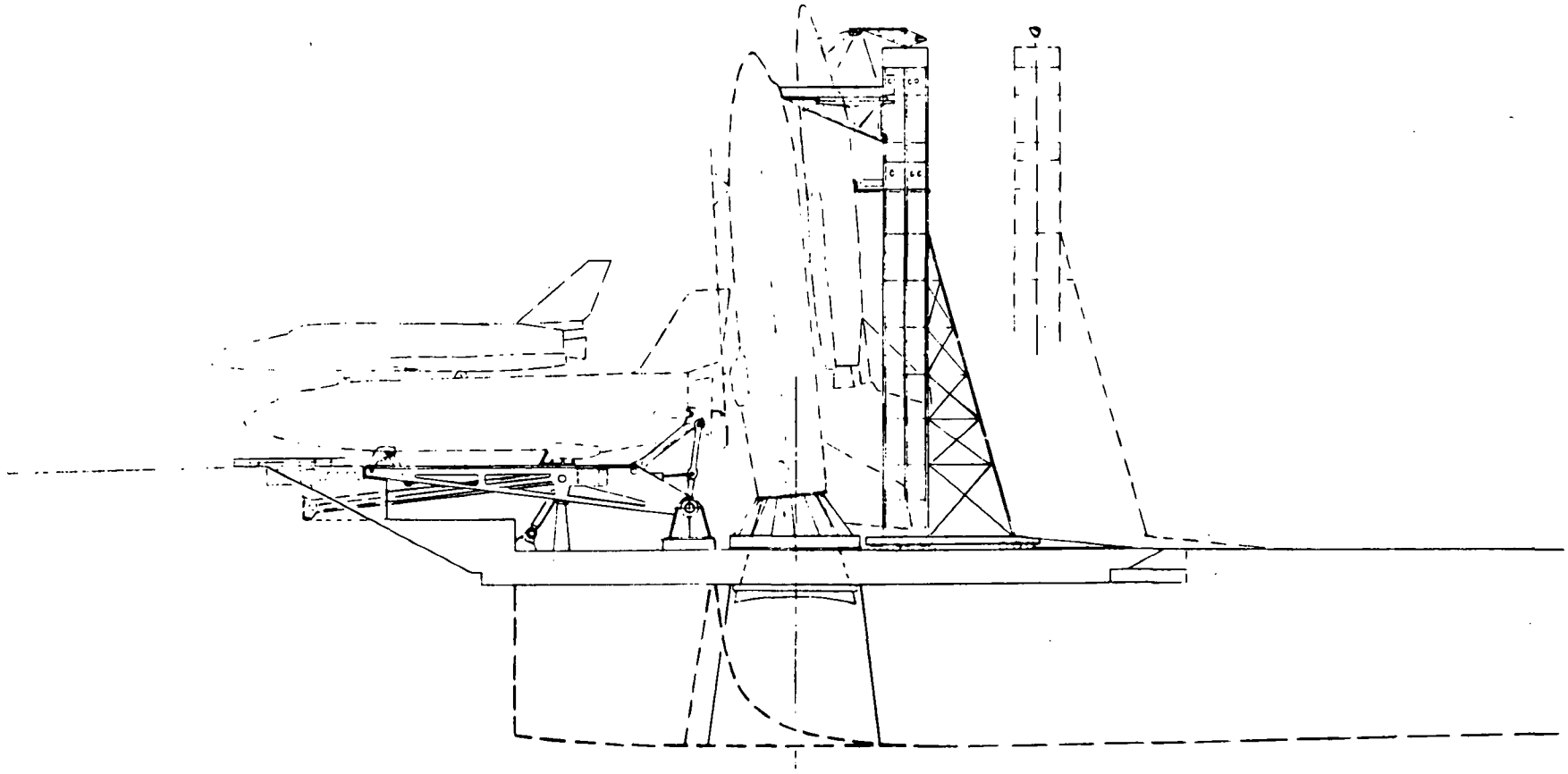


Figure 2-59. Launch Pad Erection, Bascule Concept

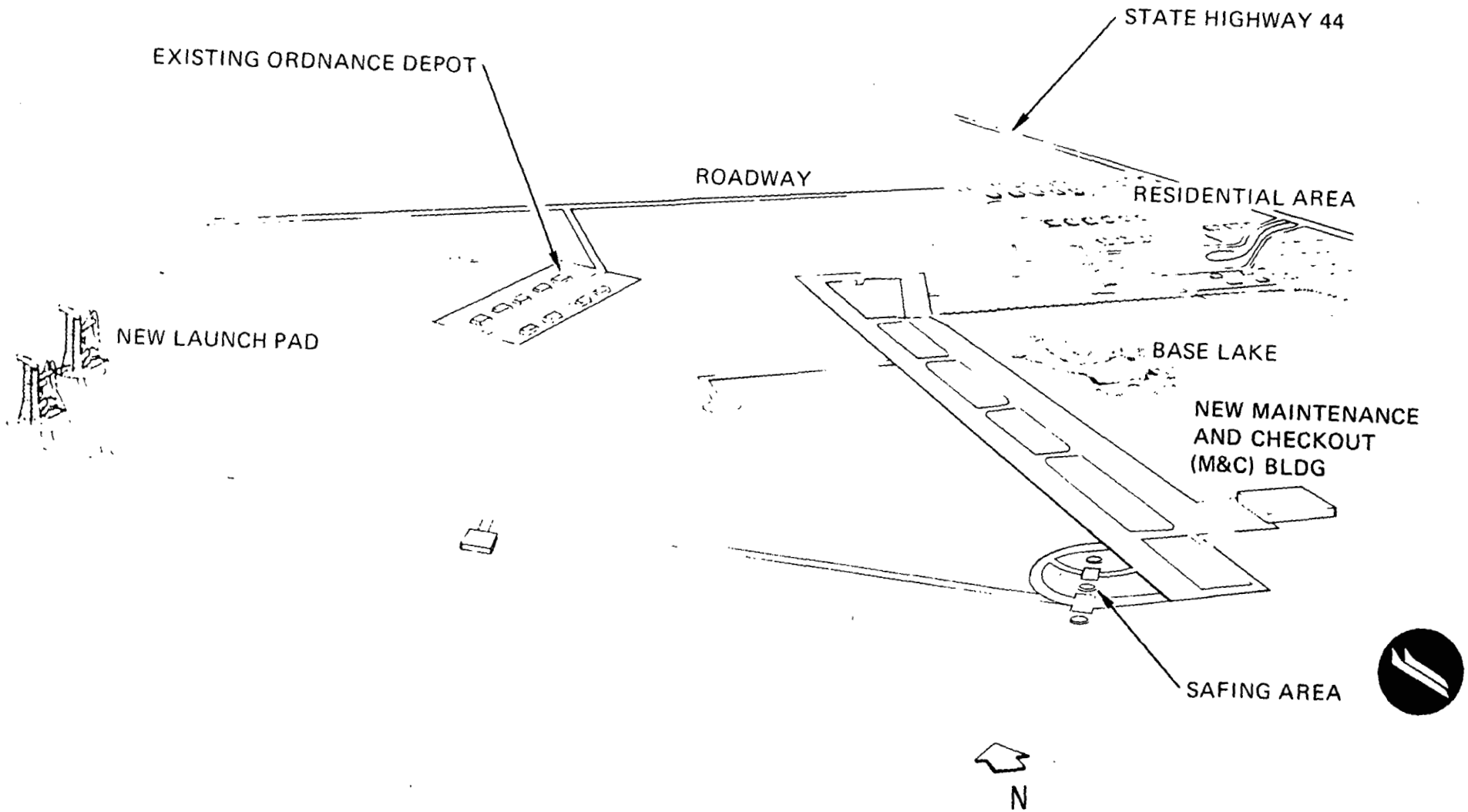


Figure 2-60. Operational Concept at Clinton-Sherman (West)

Outlying buildings would have to be built for propellant, pyrotechnic, and radioactive material support, as existing buildings do not have adequate separation for safety of personnel.

Vehicle mating would be accomplished in a maintenance and checkout building addition or in a mating fixture similar to that shown in Figure 2-61. Such a mating fixture could be considered only at sites with good weather and would probably still require some weather protection covering. A 4-1/2-mile towway would be required to tow the mated vehicles to the launch pad, where the erectors would be located.

An entire, new launch complex also would have to be constructed at Edwards, including two launch pads with service towers, propellant storage and loading systems, gas storage and loading system, and utility support. A new launch control center would have to be built, and new tracking, communication and range safety systems would have to be installed. The recommended location for the new launch complex is near Rogers Dry Lake, about 4-1/2 miles east of Building 1623, the present C-5A hangar (Figure 2-62).

The landing facility at Edwards meets the Space Shuttle requirement. The runway is 15,600 feet long and excellent landing systems support is available. A new safing area would be constructed at the southeast end of the runway.

Maintenance and checkout of two orbiters could be accomplished in the existing C-5A hangar, which is 220 feet by 300 feet with an 85-foot clear height. A new 140,000-square-foot building would have to be constructed adjacent to Building 1623 for booster maintenance and checkout.

Storage of three orbiters could be accomplished in Building 1600 with slight modification for tail clearance. A 100,000-square-foot building would have to be constructed for booster storage. Many support functions exist at Edwards and are adequate for the space shuttle; however, some additions, such as hardware cleaning and repair and training facilities would be required in the specialty areas.

2.5.5 Holloman Air Force Base

Building 310 at Holloman Air Force Base could be modified to clean-room standards and used for payload preparation. Existing outlying buildings would be used for propellant, pyrotechnic, and radioactive material preparation. The orbiter would be mated to the booster horizontally in the new maintenance and checkout building. Towing mated vehicles to the launch pad in a horizontal position would require construction of a 60-foot-wide, eight-mile-long tow-way to the launch pad. Each launch pad would have an erector to position the vehicles on the launch pad.

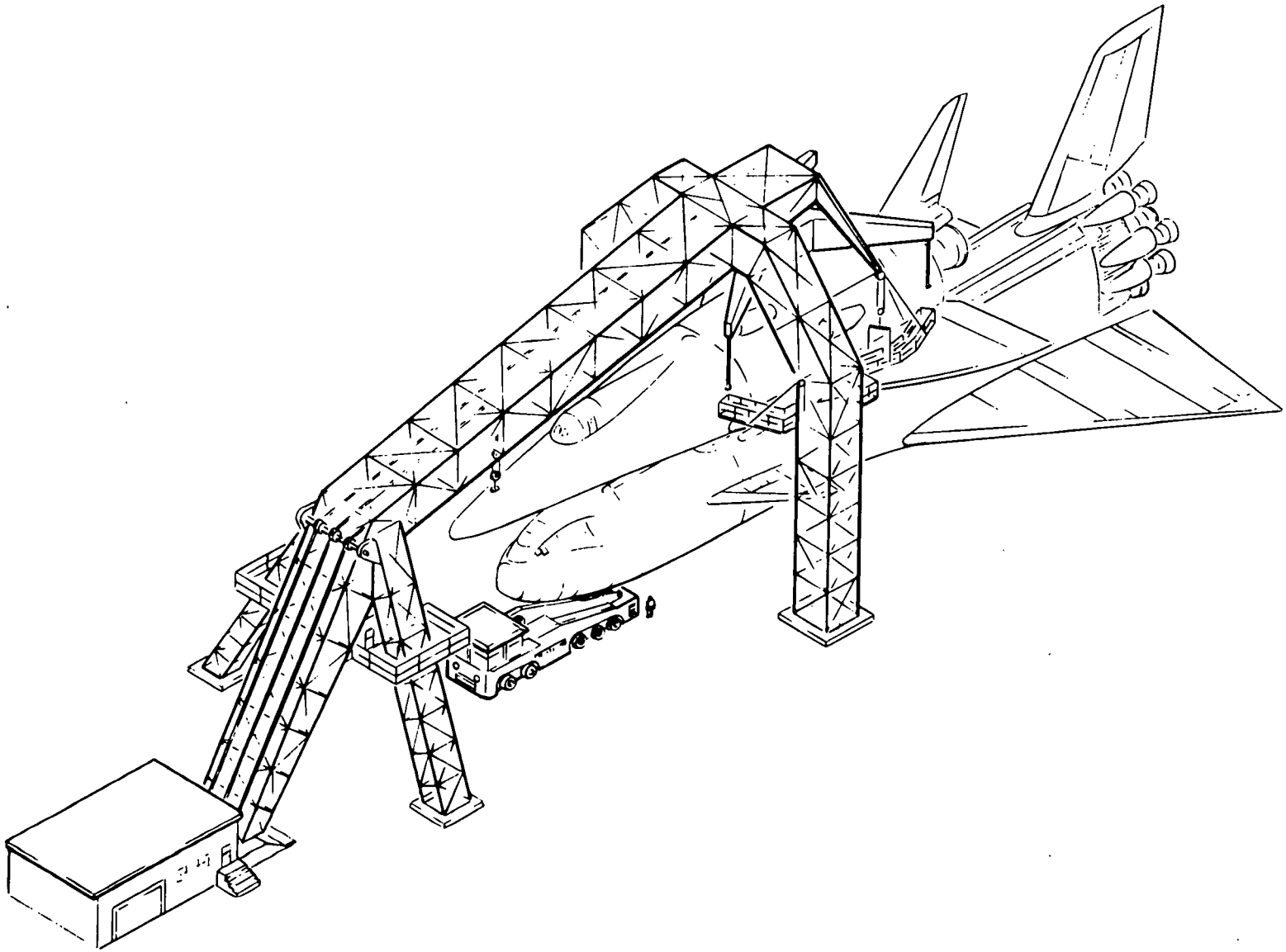


Figure 2-61. Horizontal Mating Device

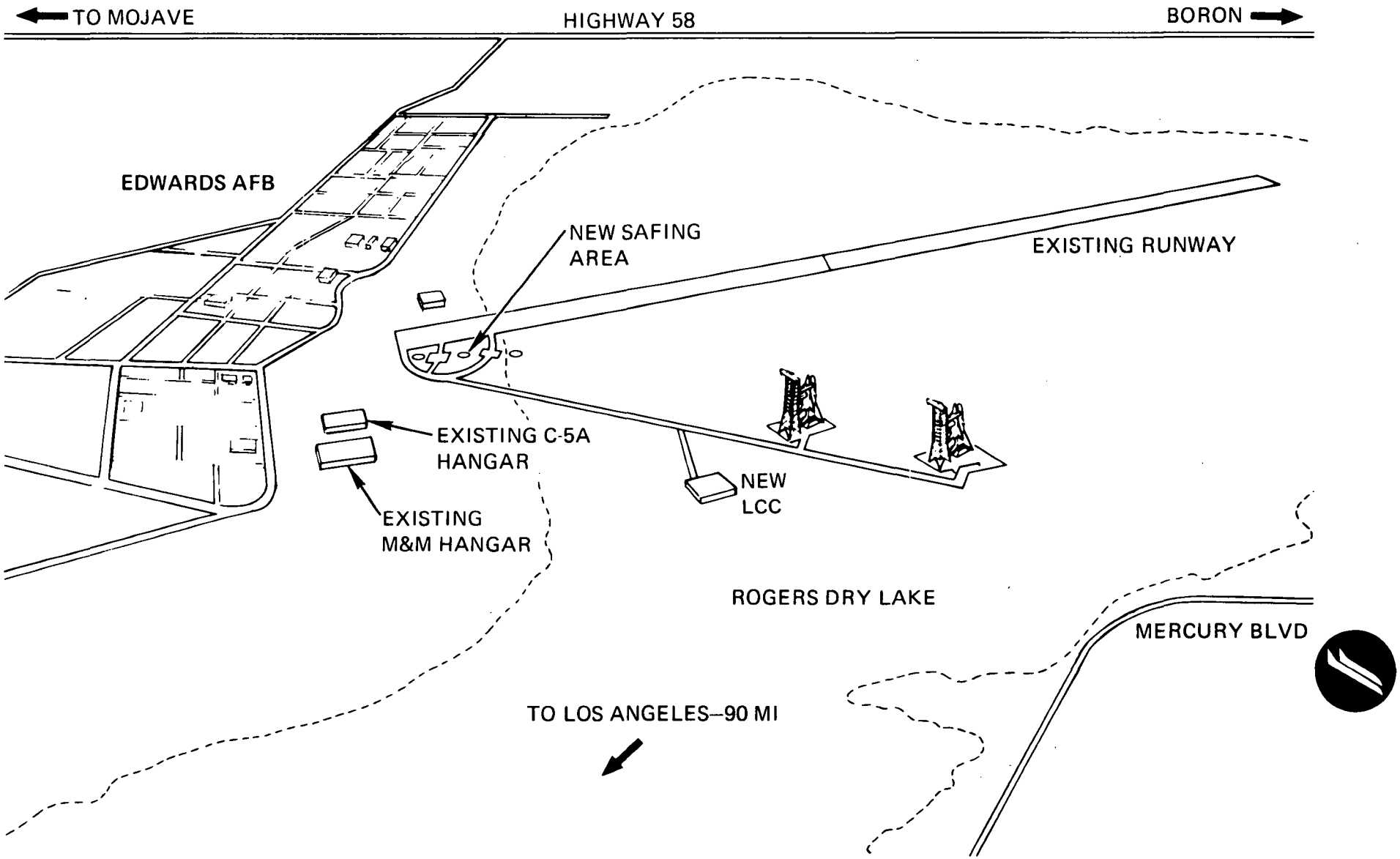


Figure 2-62. Operational Concept at Edwards AFB (Rogers Lake)

Launch facilities exist at White Sands Missile Range (WSMR) 35 miles southwest of Holloman AFB. These facilities, however, are not adequate for the space shuttle and are not close enough to an existing air-field to be considered for modification. A new launch complex would be required in the Malone Draw area approximately eight miles due north of the main base (Figure 2-63). Tracking and data acquisition facilities at WSMR and Holloman AFB could be used.

The 12,200-foot runway at Holloman would have to be extended by 1000 feet and overlaid for increased strength as its bearing capacity is not acceptable for the booster support. A new safing facility would have to be constructed at the northwest end of the runway.

None of the buildings at Holloman are large enough for maintenance and checkout activities. A new 230,000-square-foot building with the noted clear heights would have to be constructed north of the runway. To accomplish horizontal mating, a 150-ton crane with a 120-foot hook height would have to be provided in one bay of the new building. A 180,000-square foot building would have to be constructed to store two boosters and three orbiters. It would be contiguous with the maintenance and checkout building.

Support facilities exist in most areas. Some building modifications would be required to meet space shuttle requirements.

2.5.6 Kennedy Space Center

Payload preparation could be accomplished at the Kennedy Space Center in the assembly and test area of the Manned Spacecraft Operations Building (MSOB). This area meets Class 100,000 clean conditions and has a 40-ton crane with an 85-foot hook height. Buildings 1210, 1212, 1410 and 1412, located just northwest of the MSOB, are adequate for propellant, pyrotechnic, and radioactive material activities.

The booster and orbiter will be erected to the vertical position, mated, and positioned on a missile launcher in the Vertical Assembly Building (VAB); crane and door modifications are required. Existing crawlers and crawlerways are adequate to transport the mated vehicles to the launch pad.

Launch Complex 39 will be used. Pads 39A and 39B require some modification. An additional LH_2 storage tank is needed at each pad, and JP fuel storage and pumping facilities must be installed. The existing launch control center and launch support systems are generally adequate.

A new landing facility must be constructed at KSC to meet space shuttle requirements. The runway will be located west of the VAB as shown in Figure 2-64. A new safing facility will be constructed at the north end of the runway.

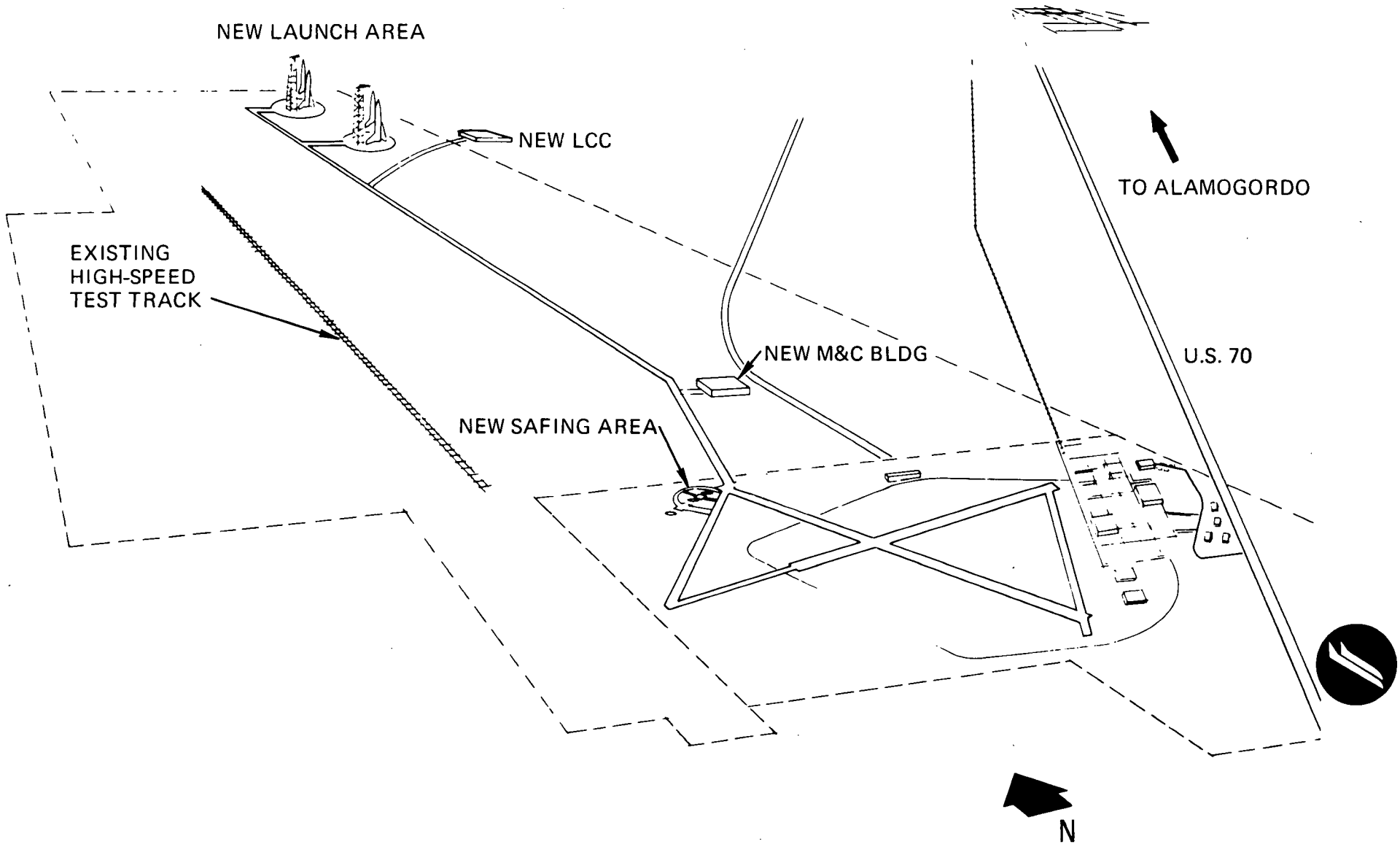


Figure 2-63. Operational Concept at Holloman AFB (North Base)

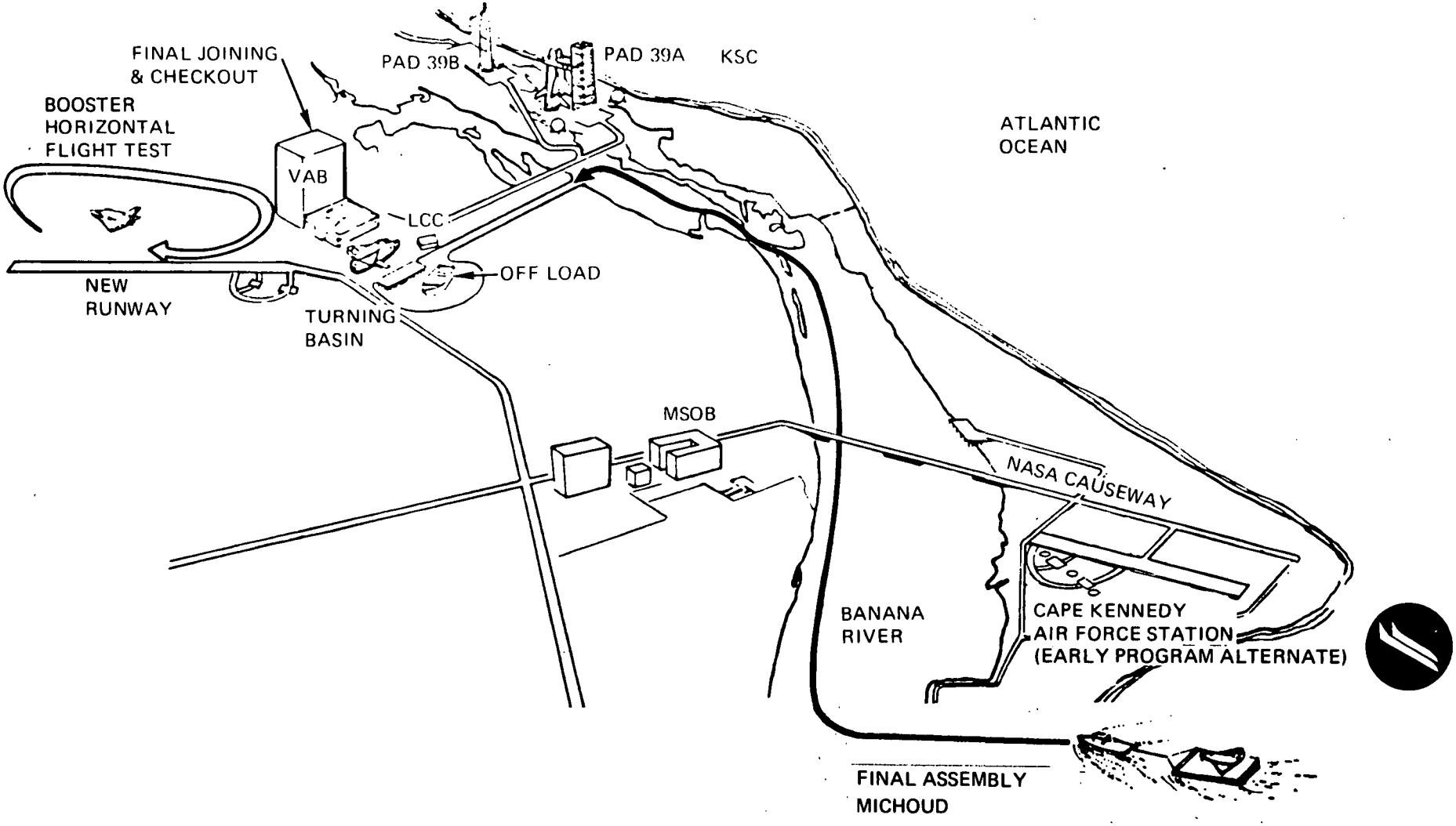


Figure 2-64. Operational Concept at KSC (LC 39)

Two cells of the VAB are adequate for orbiter maintenance and checkout. A new 140,000-square-foot building contiguous with the north wall of the VAB is required for booster maintenance and checkout. One orbiter can be stored in the VAB; and a new building is required for storage of two boosters and two orbiters. Supporting activities at KSC are adequate with few exceptions.

2.5.7 Wendover Auxiliary Air Force Base

Wendover Auxiliary Air Force Base (inactive) also is a former SAC operations base. It is located approximately 125 miles west of Salt Lake City. The existing main hangar building can be modified for payload processing by addition of a crane and conversion to clean-room condition after considerable refurbishment. New outlying buildings must be built for hazardous activities.

The orbiter would be mated to the booster horizontally in the new maintenance and checkout building. The mated vehicles would be towed to the launch pad over an 80-foot-wide, seven-mile-long tow-way, which would have to be constructed. An erector must be constructed at each launch pad.

No launch capability exists at Wendover, and a complete new launch complex would be constructed west of the Nevada-Utah state line southwest of the main base hangars. The location is shown in Figure 2-65.

The 9,100-foot runway at Wendover would have to be lengthened by 4,000 feet and would have to be strengthened to accept booster landing loads. A new safing facility would be constructed at the southwest end of the runway.

A new 230,000-square-foot building with the noted clear heights would have to be constructed for maintenance and checkout. Existing buildings at Wendover do not provide the required bay sizes and clear heights and, other than the main hangar, are obsolete. The recommended site for this new building is along the west side of the runway. To accomplish horizontal mating, a 150-ton crane with a 120-foot hook height must be provided in one bay of the new building.

A 180,000-square foot building contiguous with the maintenance and checkout building, would have to be constructed to store two boosters and three orbiters. Substantial facility additions also would be required to provide the support functions needed for the operations activity. Laboratories would have to be constructed and facilitized as would buildings for training, crew and passenger quarters, and support shops.

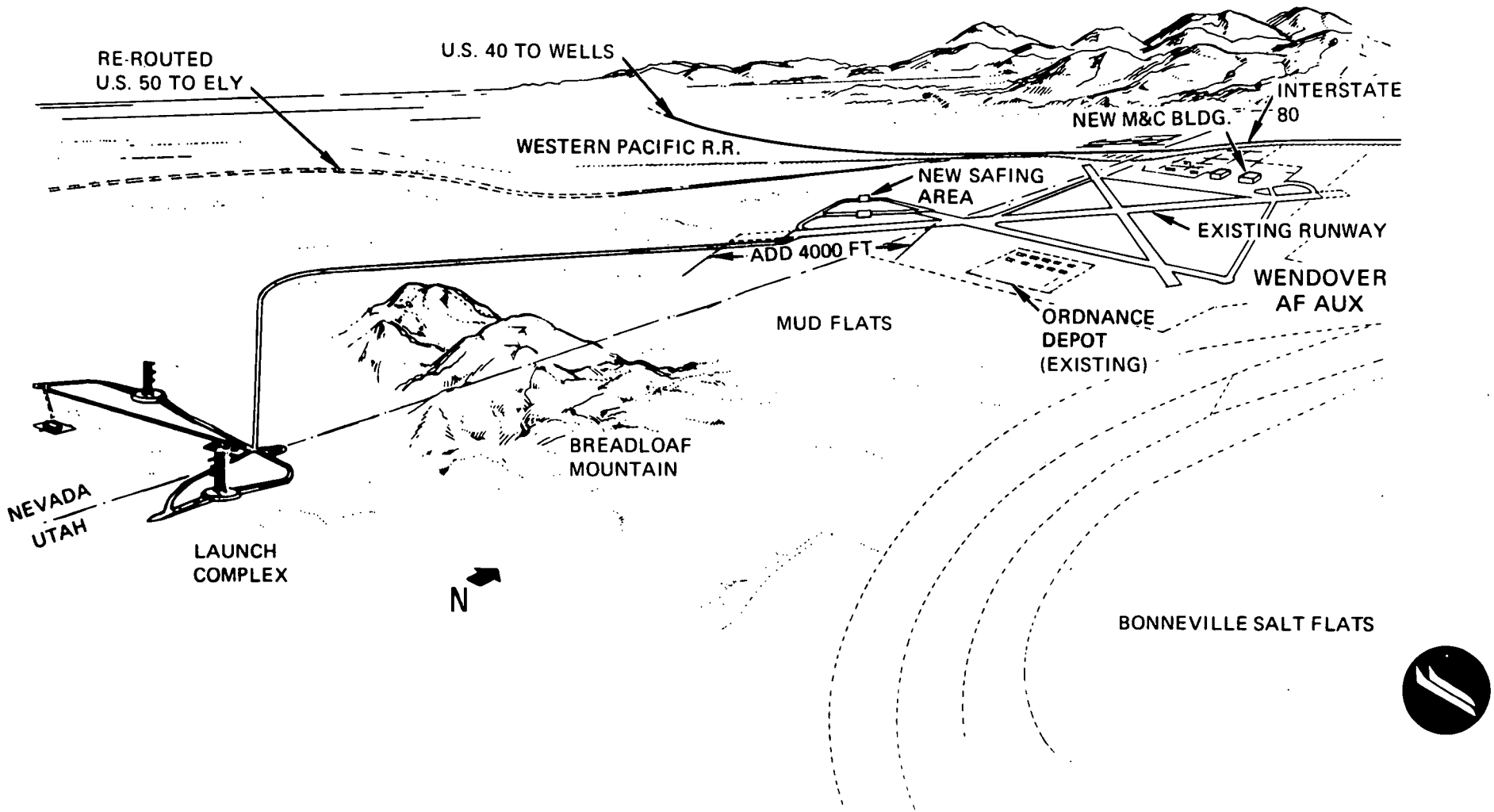


Figure 2-65. Operational Concept at Wendover, Bombing Range

2.5.8 Western Test Range (Vandenberg Air Force Base)

A relatively undeveloped area northwest of the runway at the Western Test Range (WTR) would be used for space shuttle operations. Many other WTR areas were considered, some having existing and partially applicable facilities. The preferred area is nearly on the beach; it is bounded on the south by San Antonio Creek and is presently considered to be the most cost- and program-effective location. Figure 2-66 shows the vicinity and facility concept at the Western Test Range.

To avoid schedule interference and security problems, an existing building would be modified for payload preparation. Buildings exist for the hazardous activities, although some are quite remote from the site.

The horizontal mating concept would be used at WTR and would be performed in the new maintenance and checkout building. Erectors would be constructed at the launch pads. A five-mile tow-way would have to be built.

Two new launch pads with service towers would be built 1,000 yards north of San Antonio Creek. Propellant and gas storage and transfer systems and a launch control building would be constructed. Most of the required launch support systems exist.

The runway at Vandenberg AFB is 8,000 feet long and would require a 2,000-foot extension, and fifty-foot shoulders should be added. The bearing capacity is marginal and the field would require strengthening. A new safing facility would be constructed at the northwest end of the runway. A new 230,000-square-foot building would be constructed beside the runway for maintenance and checkout. To accomplish horizontal mating, one bay of the building would require a 150-ton crane with a 120-foot hook height.

A 180,000-square foot building would have to be constructed contiguous with the maintenance and checkout building to store two boosters and three orbiters. WTR has a broad range of support activities applicable to the Space Shuttle program; however, some additional facilities will be required to avoid interference with USAF programs.

The Southern Pacific Railroad runs through the Vandenberg area. A careful study should be made of the impact of trains on launch schedules before this area is selected as the launch site. It may be advisable to reroute the tracks to the east.

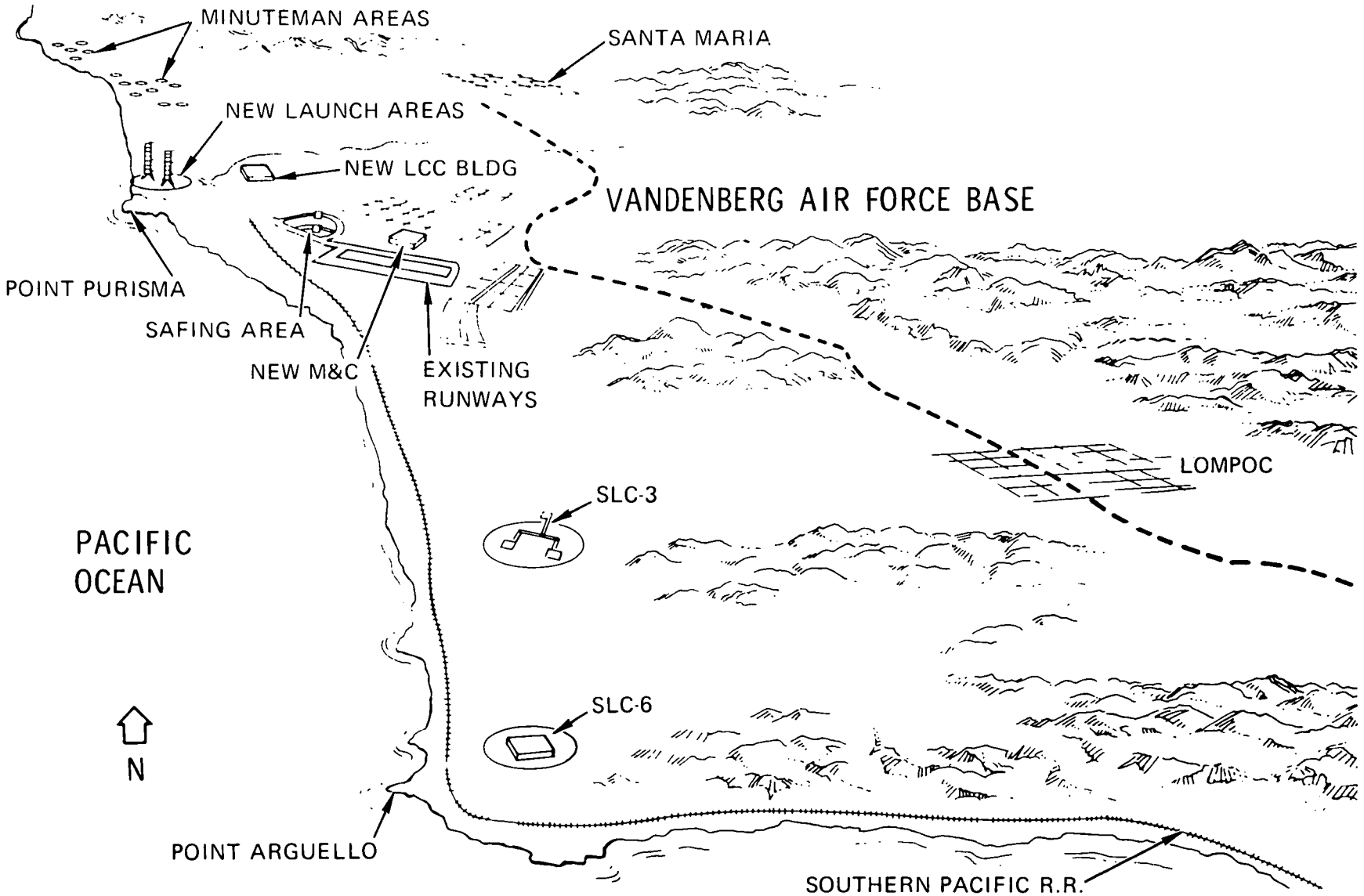


Figure 2-66. Operational Concept at WTR (San Antonio Creek)

2.5.9 Summary and Recommendations

The site evaluation study indicated KSC to be the best of the six sites for vertical flight test as well as for operations activity. A summary of the facilities implementation is given in Table 2-15. The reasons for the KSC recommendation are summarized as follows:

Vertical Flight Test Advantages

1. Easterly launch advantages:
   a. Easterly launch azimuths over the ocean afford maximum earth rotational velocity.
   b. No population overflight risk.
   c. No exposure of population to booster sonic boom.
   d. No air traffic interference.
   e. No foreign overflight by booster.
   f. Orbiter recovery sonic boom could be minimized by landing at McDill or Eglin AFB and ferrying back to the launch site.
2. Satisfactory booster abort recovery options.
3. Satisfactory orbiter abort recovery options for mated ascent.
4. Excellent orbiter abort recovery options for first revolution from 200- to 1,100-nautical-mile crossrange.
5. KSC exclusively affords second-revolution abort recovery options for 200-nautical-mile crossrange.
6. KSC permits maximum use of existing facilities.
7. An operating national range and spaceflight center exists.
8. Payload and transfer stage support shops available.
9. VAB can be used for maintenance, erection, and mating.
10. LC-39 launch pads require only minor modification.
11. Crawler-transporter and modified mobile launcher available.

12. KSC is the only site with existing barge capability to permit booster assembly and major refurbishment at Michoud.

13. The required modifications and existing capability affords the lowest facility costs, particularly in early funding requirements.

14. Reduces schedule risk.

Operations Advantages

1. Retains all the advantages of vertical flight test capability and experience and retains continuity of personnel, hardware, and software at a single site resulting in increased program efficiency, minimized program costs, and minimized program schedule risk.

2. Maximum due-east payload capability with the vehicle only slightly larger than required at an inland site.

3. Equal or higher payload capability on other than due-east missions.

4. Low latitude offers significant advantages for synchronous equatorial and other low-inclination orbits.

5. A vehicle sized for 40,000-pound polar orbit meets or exceeds preliminary traffic model requirements for all missions.

6. Initial facility costs are lower than for other sites.

7. Only KSC has barge access to a major NASA site (Michoud) for possible future major hardware needs; e.g., additional vehicle, major assembly refurbishment, or replacement assemblies.

Use of WTR for Southerly Launches

If booster reentry or sonic boom or subsonic cruise flyback over Cuba is not acceptable, the study recommended that southerly launches be made from the Western Test Range, which offers the following advantages:

1. Ocean overflight for south polar and southwest sun-synchronous azimuths.

2. No population overflight risk.

3. No exposure of population to booster sonic boom.

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Table 2-15. Ground Operations Facilities Summary

Facility	Clinton-Sherman AFB	Edwards AFB	Holloman AFB	Kennedy Space Center	Wendover AFB	Western Test Range
1. Maintenance and Checkout (M&C)	Build new 230,000-square-foot building, 70 to 120 feet high, 50-ton cranes, East of runway.	Use Building 1623 for orbiter. Construct 140,000 square-foot building, 70 to 120 feet high, 20-ton cranes next to Building 1623.	Build new 230,000-square-foot building, 70 to 120 feet high, 150-ton cranes, North of runway.	Orbiter use two existing bays of VAB. For booster construct new 140,000-square-foot building, 70 to 120 feet high, 20-ton cranes adjacent to VAB.	Build new 230,000-square-foot building, 70 to 120 feet high, 150-ton cranes, North side of runway.	Build new 230,000-square-foot building, 70 to 120 feet high, 150-ton cranes, North side of runway.
2. Vehicle Storage	Build new 180,000-square-foot building, 70 to 120 feet high, next to M&C Building.	Use Building 1600 for orbiters. Add 100,000-square feet, 70 to 120 feet high, for booster.	Build new 180,000-square-foot building, 70 to 120 feet high, next to M&C Building.	Build new 180,000-square-foot building, 70 to 120 feet high, next to M&C Building.	Build new 180,000-square-foot building, 70 to 120 feet high, next to M&C Building.	Build new 180,000-square-foot building, 70 to 120 feet high, next to M&C Building.
3. Cargo Processing	Modify Building 101 to 30-ton crane, 32,000-square feet of class 100,000 clean room.	Convert Building 1207 and 1210	Convert Building 310	Use MSO Building (adequate)	Convert Hangar Building	Modify existing hangar building.
4. Pyrotechnics and Cargo Propellants	Modify outlying buildings.	Build new buildings.	Modify outlying buildings.	Use Buildings 1210, 1212, 1410 and 1412 (adequate)	Build outlying buildings.	Modify outlying buildings.
5. Vehicle Mating	Horizontal in new M&C Building.	Construct horizontal mating framework	Horizontal in new M&C Building	Vertical in VAB cell; widen doors	Horizontal in new M&C Building	Horizontal in new M&C Building
6. Vehicle Erecting	Build erector at each pad	Build erector at each pad	Build erector at each pad	In VAB cell, add 250-ton crane, remove platfrom, add dolly rails and line	Build erector at each pad	Build erector at each pad
7. Transporting	Need new 4-1/2 mile tow way, nose transporter, and movers.	Need new 4-1/2 mile tow way, nose transporter, and movers	Need new 8-mile tow way, nose transporter, and movers	Use existing crawlers and crawlerway; modify mobile launchers	Need new 7-mile tow way, nose transporter, and movers	Need new 5-mile tow way, nose transporter, and movers
8. Launch Pads	Construct two new pads and service towers West of Ordnance Depot	Construct two new pads and service towers near Rogers Dry Lake	Construct two new pads and service towers 8 miles North of runway	Use Pads 39A and 39B with minor modification; use mobile launchers.	Construct two new pads and service towers 7 miles Southwest of main base	Construct two new pads and service towers 1000 yards North of San Antonio Creek
9. Propellant, Gas, and Utility Systems	Construct new at each pad	Construct new at each pad	Construct new at each pad	Double LH_2 capacity, add JP capacity, LO_2 adequate, rest generally adequate	Construct new at each pad	Construct new at each pad
10. LCC Tracking Communication, Range Safety, etc.	Construct new facilities	Construct LCC, add to systems	Construct LCC, use WSMR systems, some additional facilities required	Use existing LCC and systems	Construct new facilities	Construct LCC, use existing systems, some additional required
11. Airfield and Landing Systems	Use existing facilities	Use existing facilities	Lengthen runway by 1000 feet and strengthen	Construct new facility 1 mile West of VAB or use CKAFS	Add 4000 feet and strengthen runway, some new systems	Add 2000 feet, add 50-foot shoulders, and strengthen runway
12. Safing Facility	Construct new facilities	Construct new facilities	Construct new facilities	Construct new facilities	Construct new facilities	Construct new facilities
13. Crew Training and Quarters	Complete modification of existing buildings	Modify existing buildings and construct new buildings	Complete modification of existing buildings	Expand existing facilities	Construct new facilities	Modify existing buildings and construct new
14. Supporting Offices, Laboratories and shops	Substantial additions required	Some additions required	Some additions required	Generally adequate	New facilities required	Some additions required

4. No exposure of population to orbiter sonic boom, with a reentry avoidance maneuver.

5. No air traffic interference.

6. No foreign overflight.

7. Utilization of existing facilities, including Western Test Range personnel and equipment, DOD and scientific payload support shops some transfer stage support shops, and adaptable hangars and maintenance buildings.

8. Good local and nearby industrial support.

Facilities Cost Comparison

Comparative cost estimates for construction and equipment at the six candidate sites are given in Table 2-16. Costs associated with concurrent use of both KSC and WTR are not estimated.

2.5.10 Implementation of Recommended Operations Site

The following facility analyses are based on the use of KSC as the operations site. It should be noted that KSC also has been recommended for booster final assembly, checkout, and horizontal flight testing. The discussions herein, however, are confined to vertical flight test and operations facility requirements only.

Payload Processing Facilities

The main payload preparation activity is planned for the Manned Spacecraft Operations Building (MSOB) at KSC. The assembly and test area of the MSOB has the required Class 100,000 clean environment and 40-ton crane service with 85-foot hook height. Adjacent shops and laboratories are available for payload preparation. Figure 2-67 indicates the planned use of the assembly and test area in the MSOB.

Only nonhazardous work will be performed in the MSOB. Certain propellant loading could be done in Buildings 1210, 1212, 1410, and 1412 (Figure 2-68). The readied payload modules will be trucked to these buildings and then to the VAB or to the launch pad for loading into the orbiter vehicle.

Nonhazardous payloads will be sealed in modules in the MSOB then moved to the VAB for loading into the orbiter. It is planned to use one of the VAB low-bay cells for final payload staging prior to loading into the orbiter.

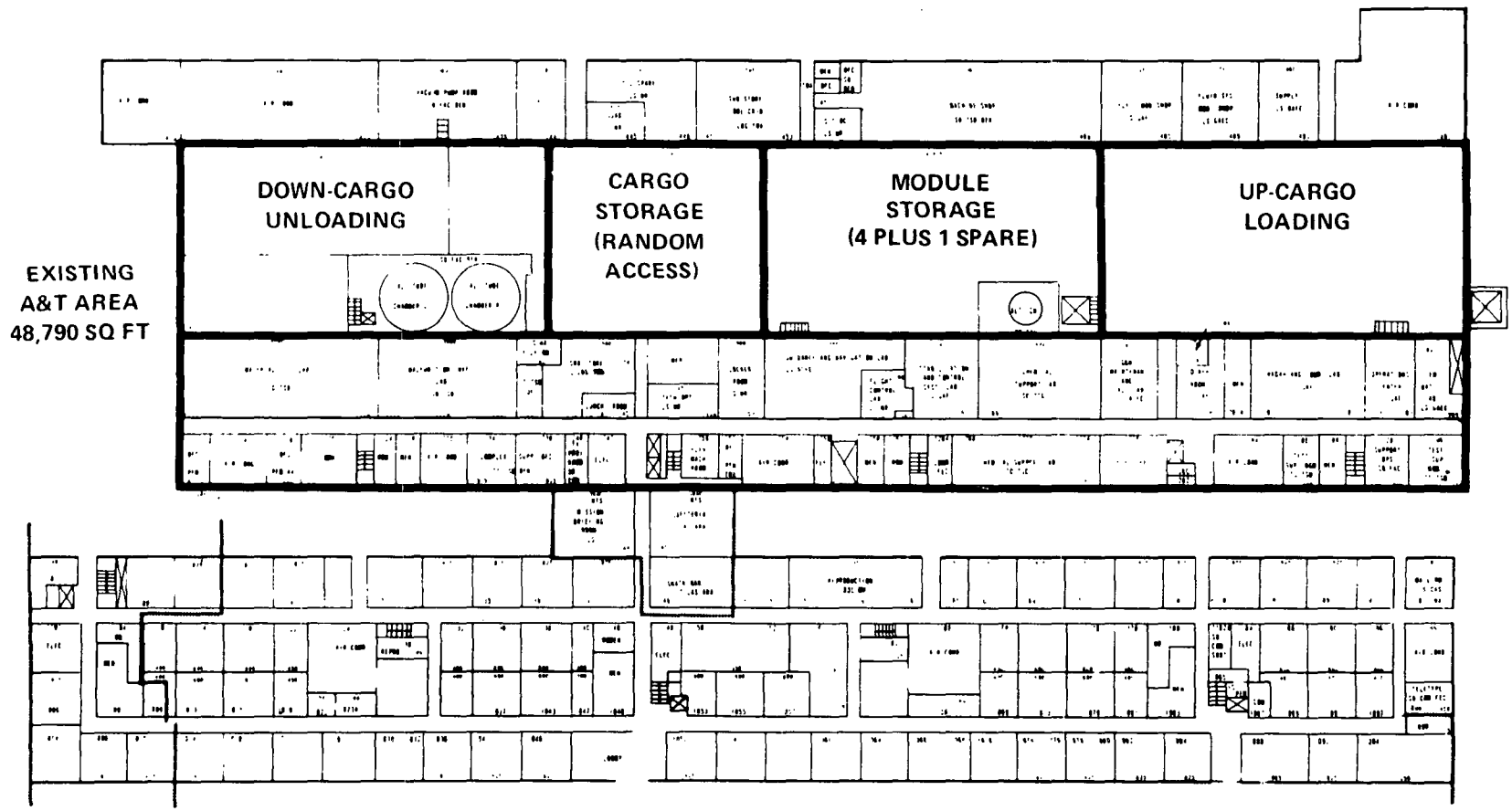


Figure 2-67. Cargo Processing Concept, MSOB KSC

Table 2-16. Operations Site Construction and Equipment Costs (1970 $ in Millions)

Facility	Kennedy Space Center	Western Test Range	Holloman AFB	Wendover AFB	Edwards AFB	Clinton-Sherman AFB
CONSTRUCTION						
1. Landing facility Φ*	24.0	7.5	7.0	16.7	0.5	0.5
2. Deservice and safing area	5.0	4.1	4.5	4.9	6.0	4.5
3. Launch pads A and B	28.0	55.0	55.0	68.8	55.0	55.0
4. Cryogenic service systems	6.6	13.8	13.8	14.2	13.8	13.8
5. Mobile launcher modification (KSC only)(2 ea)	10.6	--	--	--	--	--
6. Launch control center	0.5	4.8	4.8	5.7	4.8	4.8
7. Control data processing	--	4.5	4.5	5.4	4.5	4.5
8. Maintenance, checkout, and mating facility	27.8	32.0	32.0	42.7	32.0	32.0
9. Propellant Systems Comp. Lab	--	1.0	0.8	1.6	1.3	1.3
10. Administrative and Technical offices	--	7.0	7.0	12.0	8.0	6.0
11. Flight crew training facility	1.0	2.5	2.5	3.0	2.5	2.5
12. Flight crew quarters	--	4.0	4.0	4.7	4.0	4.0
13. Passenger facility	1.7	1.5	1.5	1.9	1.5	1.5
14. Cargo processing (NASA)	0.6	2.2	1.4	2.3	2.2	1.4
15. Payload sterilization	5.0	4.4	4.4	5.0	4.4	4.4
16. Food services	--	0.7	0.7	1.0	0.7	0.5
17. Medical facility	--	0.7	0.7	1.9	0.7	0.9
18. Central fire station	--	--	--	0.6	--	0.2
19. Warehousing	--	2.0	2.0	2.5	2.0	1.0
20. Base support facility	--	0.2	--	2.0	0.2	0.5
21. Communications and data cabling (PAD to LCC)*	5.0	3.2	3.2	3.7	3.2	3.2
22. Tow-way (crawler-way at KSC)*	--	6.4	8.0	7.9	5.0	5.0
23. Roads and parking*	3.1	3.4	5.0	6.5	5.0	4.0
24. Base utilities (W, S, H, P)*	2.5	6.0	8.0	14.0	11.0	8.0
25. Motor and heavy equipment facility	--	0.3	0.3	0.6	0.3	0.4
26. Miscellaneous support facilities (laboratories, etc.)	5.0	8.0	8.0	30.0	16.0	7.0
27. Radar facility	--	0.5	0.5	2.0	0.5	1.0
28. Unified S-band communication facility	--	1.7	1.7	1.8	1.7	1.7
29. Miscellaneous off-site costs # θ	Unknown	(75.0)	Unknown	(5.0)	Unknown	Unknown
30. Propellant manufacturing plant #	(33.6)	(30.1)	(30.1)	(33.6)	(30.1)	(30.1)
Subtotal, construction cost	126.4	177.4	181.3	263.4	186.8	169.6
Miscellaneous items 15%	19.0	26.6	27.2	39.5	28.0	25.4
Design, supervision, and administrative 15%	21.8	30.6	31.3	45.4	32.2	29.3
Estimated design/ construction cost	167.2	234.6	239.8	348.3	247.0	224.3

Φ Equivalent to 10,000-foot sea-level runway.
* Activation costs not added for these items.
# Off-site power and gas supply costs not included.
Paren costs not included in totals.
θ $75M SPRR Relocated at WTR, $5.0M U.S. Highway 50 Relocated at Wendover.

Table 2-16. Operations Site Construction and Equipment Costs (1970 $ in Millions) (Cont)

Facility	Kennedy Space Center	Western Test Range	Holloman AFB	Wendover AFB	Edwards AFB	Clinton-Sherman AFB
EQUIPMENT						
1. Landing facility (ILS only)	0.5	0.1	0.1	0.6	--	0.1
2. Tow tugs ($165,000 each)	--	0.5	0.5	0.5	0.5	0.5
3. Maintenance, checkout and mating facility	8.0	8.0	9.0	10.0	8.0	9.0
4. Launch pad electronic equipment	1.0	2.8	2.8	2.8	2.8	2.8
5. Umbilical tower outfitting	12.0	12.0	12.0	14.0	12.0	12.0
6. LCC electronic equipment	5.0	11.5	11.5	13.0	11.5	11.5
7. Central data processing equipment	5.0	5.0	15.0	20.0	15.0	20.0
8. RF checkout equipment	--	0.2	0.4	0.5	0.4	0.5
9. Payload processing and sterilization equipment	0.5	0.9	0.8	0.9	0.9	0.9
10. Flight crew training facility	35.0	40.0	40.0	40.0	37.0	40.0
11. Administrative and technical offices	--	2.0	1.8	2.3	2.0	2.3
12. Propellant system components lab	0.5	4.5	4.5	6.5	5.5	6.5
13. Miscellaneous lab and test equipment	1.0	1.0	1.5	2.0	1.0	2.0
14. Medical facility	--	0.2	0.2	0.5	0.2	0.5
15. Food service equipment	--	0.2	0.2	0.4	0.2	0.3
16. Fire fighting equipment	0.5	0.4	0.4	0.9	0.2	0.9
17. Warehousing equipment	--	0.3	0.2	0.5	0.5	0.5
18. Engine maintenance equipment (shuttle)	2.0	2.0	2.0	4.0	2.0	4.0
19. Motor and heavy equipment pool	--	1.0	1.0	2.0	1.0	2.0
20. Base maintenance and engineering shops	0.5	0.5	0.5	2.3	0.5	2.3
21. Radars	2.0	2.0	2.0	8.0	--	8.0
22. Intercept ground operation recorder	--	--	1.9	1.9	--	1.9
23. Unified S-band equipment	--	3.4	3.4	3.4	3.4	3.4
24. Mobile cine-theodolites	--	1.1	1.1	3.3	1.1	3.3
Subtotal, equipment cost	73.5	99.6	112.8	140.3	105.7	135.2
Total construction and equipment cost	240.7	334.2	352.6	488.6	352.7	359.5
Activation cost (32% of above)	65.3	97.9	103.1	140.9	104.3	108.0
Total estimated cost	306.0	432.0	457.0	630.0	457.0	468.0

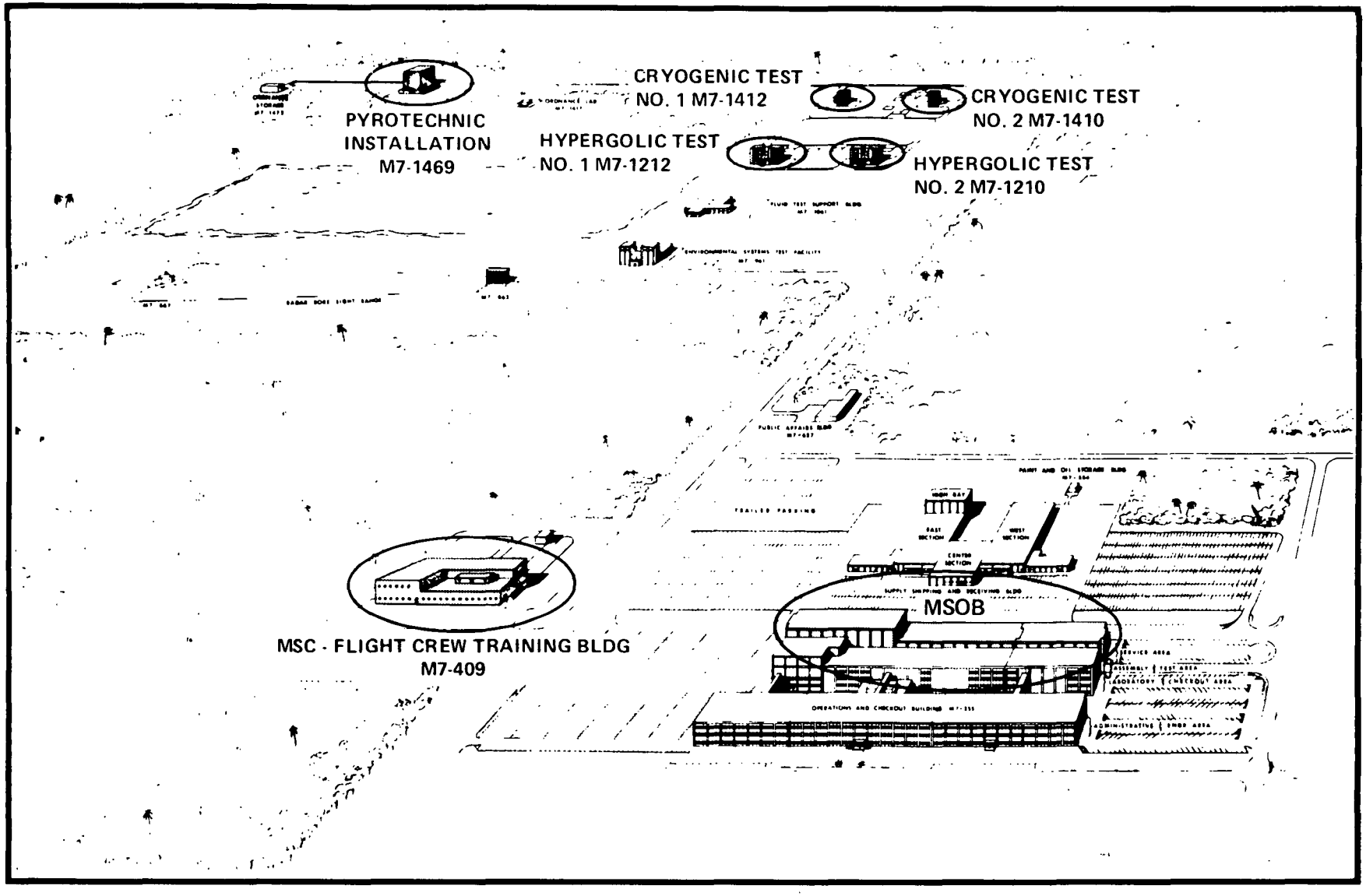


Figure 2-68. KSC Industrial Area

Integration and Mating Facilities

It was concluded following a study of erecting and mating alternatives that the space shuttle vehicles should be erected to the vertical position, mated and placed on a mobile launcher in the VAB at KSC as shown in Figure 2-69. To meet these handling requirements, the following modifications are needed in one of the high-bay cells at the VAB:

1. A second 250-ton crane must be added, riding on the existing rails at the top of the bay. An alternative approach is the addition of a 250-ton movable counterbalance, which would permit splitting of the load and erection with the existing crane.

2. Two paneled exterior sliding doors adjacent to the vertical lift doors must be removed to a height of 100 feet and a width of 40 feet. Two new horizontal-sliding, motor-operated doors must be provided to cover this area. This modification is required to provide vehicle wing clearance as the vehicle is removed from the cell on the mobile launcher.

3. The jib crane at the 80-foot elevation and Extension Platforms U through X must be removed.

4. Some utility redistribution will be required to serve this activity and the support equipment involved.

Mobile Launchers

For the Space Shuttle Program, it is planned to use three existing Saturn mobile launchers modified as follows:

1. The upper portion of the launcher above Level 320 will be removed.

2. New swing arms with 100-pound-per-square-foot live load capacity and designed to match Space Shuttle vehicle configurations will be installed for crew, passenger, and payload access. Crew and passenger access arms should be capable of moving from the retracted position to the vehicle interface position in about six seconds for emergency egress.

3. Semi-free-fall elevators from the crew and passenger egress arms to a safe area in the launch pad will be added.

4. A set of rise-off disconnect arms will be installed.

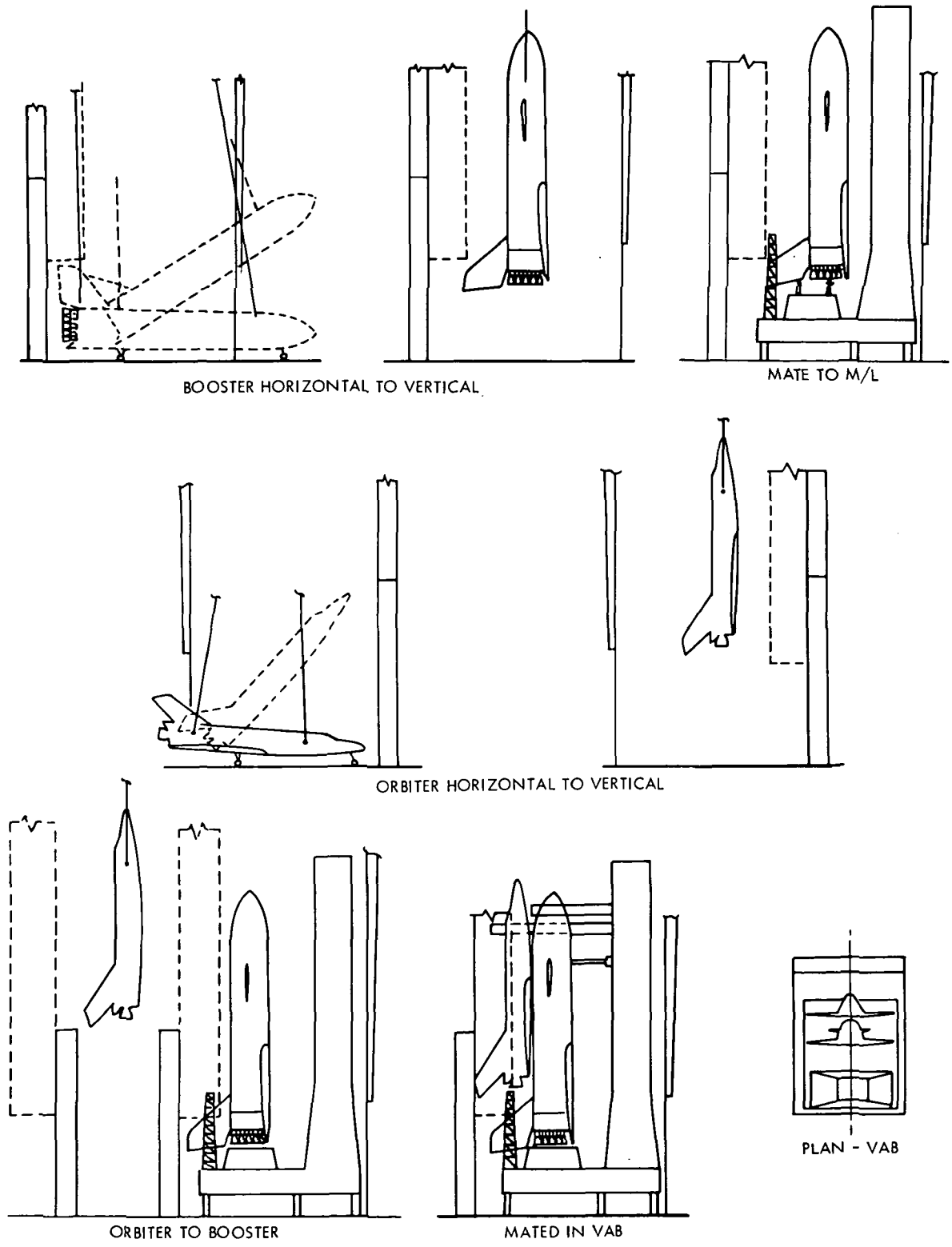


Figure 2-69. Erecting and Mating in the VAB

5. The flame opening will be modified to accept the new launch pedestal base structure.

6. Re-outfitting of systems to support the mated space shuttle vehicles will include installation of a leak-detection and warning system and fire-suppression and water-deluge equipment.

7. New propellant ducting will be installed.

8. A damper arm to the booster vehicle will be installed.

Figure 2-70 is a sketch of the modified mobile launcher.

The existing crawlers and crawlerway will be used to move the mated vehicles from the VAB to the launch pad. They are adequate for this task, although some areas of the apron and tow-way around the VAB will have to be expanded to handle the loaded crawler as it moves to the crawlerway.

Payload Changeout

Minor modification to the mobile service structure will be made to permit payload changeout on the pad.

Launch Pads

Use of the mobile launcher concept minimizes the modifications required at Pads 39A and 39B. Existing mobile launcher support pedestals, hard stand, flame trench, and flame deflectors can be used.

Some modifications will be required to the interface connections between the pad and the mobile launcher and among the environmental control, gas storage and distribution, emergency systems at the launch pad. Modifications will be needed to permit emergency egress from the elevator to a safe room.

Propellant and Gas Storage and Distribution Facilities

Existing LO_2 storage and pumping systems at Pads 39A and 39B are adequate. At each pad, an 850,000-gallon LH_2 storage sphere and distribution system will have to be added to existing systems to meet launch support requirements.

These systems should have automatic propellant flow and topping capabilities with a contingency pause and revert capability. The propellant systems must be able to dispose of propellant, especially under emergency detanking situations, and to drain and purge lines after use.

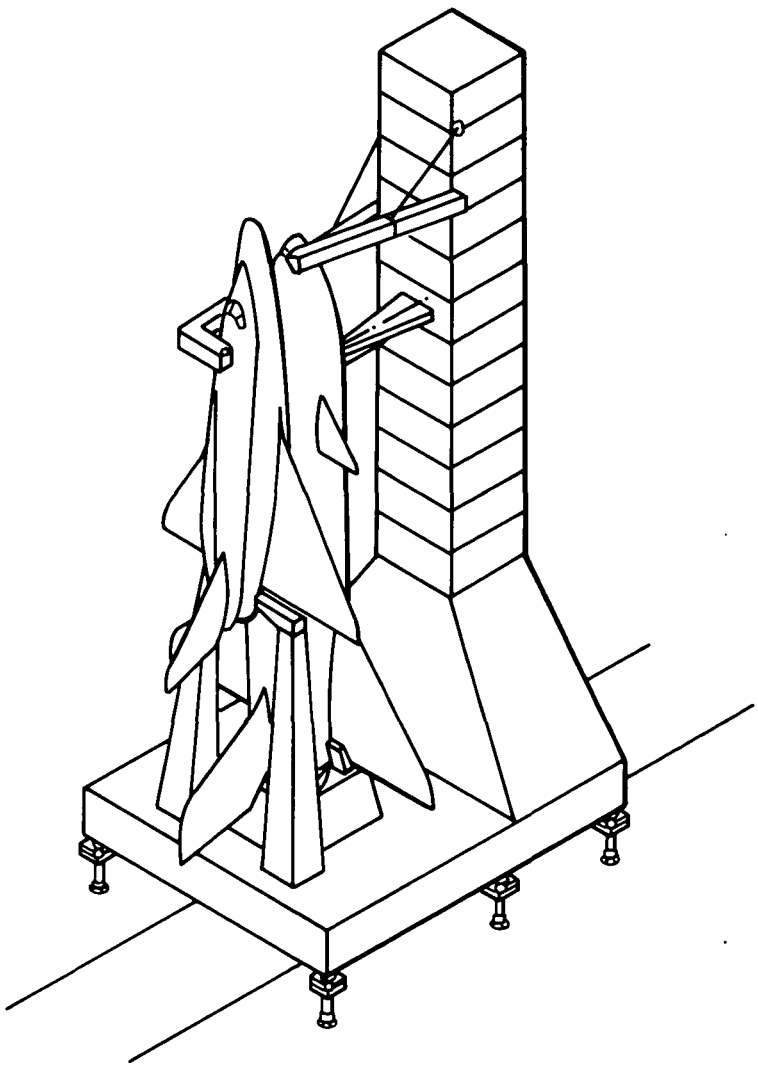


Figure 2-70. Modified Mobile Launcher

Existing RP-1 storage and supply systems, modified as necessary will be used to supply JP fuel to the vehicles.

GN_2 and GH_2 storage and supply systems are required to purge and condition the LH_2 tanks and supply lines. The LH_2 tanks will be purged with GN_2, then purged with GH_2, before loading of LH_2 begins.

Launch and Mission Control Facilities

The existing Launch Control Center (LCC) adjacent to the VAB can be used for space shuttle launches with only minor modification. Ground and flight control communication, range safety, and tracking and navigation aids exist and should be adequate. Two ground display and control system sets will be located in the LCC.

Landing Facility

As booster horizontal flight test is recommended at KSC, the main runway should be 300 feet wide by 14,000 feet long.

As no runway exists at KSC, it is proposed to construct one just over a mile southwest of the VAB approximately parallel to Kennedy Parkway. This runway should meet the following criteria:

1. 300 feet wide by 14,000 feet long.
2. Designed for 2,000 FAA Category II landings.
3. Based on the booster landing at 650,000 pounds on twin-tandem gear.
4. Portland cement concrete fixed surface.
5. Sloped down one percent to the side in each direction from the center line.
6. Surface grooved to promote rainwater runoff and improve vehicle tire traction when the strip is wet.
7. Rigid pavement overruns 1,500 feet long at each end of the runway.
8. Rigid pavement shoulder 150 feet wide on each side of the runway, sloped down one percent..
9. Threshold bars, touchdown lights, centerline lights, and edge lights.
10. An FAA Category II control tower.

11. Monitoring and directing equipment for VHF (air traffic control, approach control, ground control), tracking radar, VOR and ILS systems.

12. Three emergency vehicle access roads and emergency vehicles.

As an alternative in the first three to four years of the program, until shuttle traffic becomes heavy, the CKAFS airstrip (Figure 2-64) could be used for shuttle landing operations. This field meets the basic requirements for size and strength, but would require addition of ILS, IFT, and navigation aids to qualify as Category II. Vehicles could be transported by towing and barge from a new dock to be situated on the river north of the NASA causeway, to the VAB via the NASA channel. If the CKAFS strip is used, the cost of a new airstrip could be deferred.

Safing Facility

A safing facility is required to receive the booster or the orbiter and remove crews, passengers, and payloads; drain and safely dispose of residual propellants; purge the tanks; remove or safe pyrotechnic devices; and prepare the vehicle for towing to the maintenance and checkout facility. It is also planned that the safing area will be equipped to fuel either vehicle with JP, LH_2, and LO_2 for horizontal takeoff and air-breathing engine runup and to check out vehicle guidance system orientation. This facility will have to be constructed at KSC and should have the following features:

1. Two 400-by 400-foot concrete pads capable of supporting the booster wheel loads.

2. A valve pit, drain line, and drain basin for LO_2.

3. A drain line and burn pond for GH_2 and LH_2.

4. Vehicle area lighting to 70 foot-candles.

5. A 4,000-cubic-foot, 6,000-psi storage bank of GN_2 purge gas and a distribution system to required points on the vehicle.

6. LH_2, LO_2, JP, and storable propellant trailers and transfer systems to unload vehicles.

7. A water deluge system serviced by an eight-inch-high pressure fire main.

8. A revetted shelter and work area equipped with water, power, and sanitation facilities adequate to serve personnel who must be at the safing facility.

9. Safety showers at the pad perimeter.

10. A waste-water treatment plant.

11. Static ground rods and vehicle tie downs.

12. Work stands adjustable to a 40-foot height.

13. Mobile stairs and platforms for personnel off-loading.

14. A 30-ton-capacity truck crane (mobile, 100-foot boom).

15. Payload-handling load bars.

16. Tow tractors and tow bars.

17. A parking area for 20 vehicles.

18. A hardline to the ground display and control system in the VAB for dumping flight data.

Two safing pads may be required to accommodate peak launch rates and may be advisable in the event of an abort that would return both the booster and orbiter at nearly the same time.

Maintenance and Checkout Facility

A facility is required for inspection, maintenance, and checkout of each vehicle. In addition, storage space must be provided to house vehicles awaiting flight assignment.

Orbiter Maintenance and Checkout. Two stations are required for maintenance and checkout of orbiter vehicles. It is planned to use two existing high-bay cells in the VAB for this purpose (Figure 2-71). Only minor utility redistribution is required.

Booster Maintenance and Checkout. Two stations are required for maintenance and checkout of booster vehicles. Since the VAB cells are assigned to other functions and since they cannot house a booster without

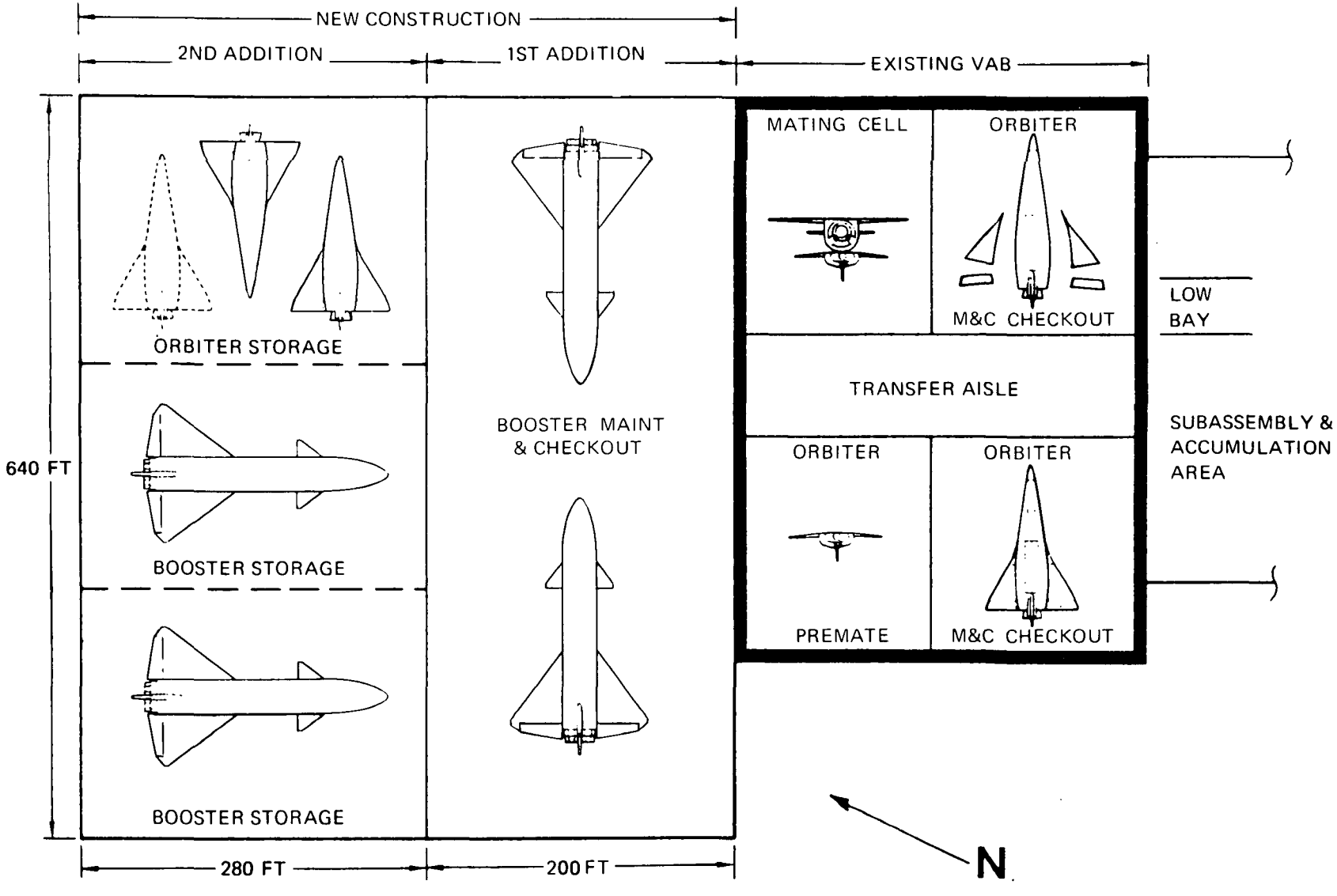


Figure 2-71. Concept Plan for Common Utilization of VAB

major modification, an addition to the VAB along its north wall is proposed. This addition should be designed to the following criteria:

1. A clear-bay width of 200 feet, 640 feet long.

2. A clear height of 120 feet over the vertical stabilizer, 70 feet elsewhere.

3. Two 20-ton cranes to cover the entire bay. Inching capability to be provided with a lift speed varying from one foot per minute to 25 feet per minute.

4. Motor-driven doors at each end of the bay.

5. Concrete sealed floors capable of withstanding booster wheel loading as shown in Figure 2-72, and containing a ground grid system.

6. Environmental control to 70 to 85 F, 50 ±5 percent relative humidity, and air filtered to 50-micron particle size.

7. Lighting to 70 foot-candles at bench height.

8. Potable water, chilled water, 90 psi filtered factory air, fire protection water, and electrical power supply and distribution.

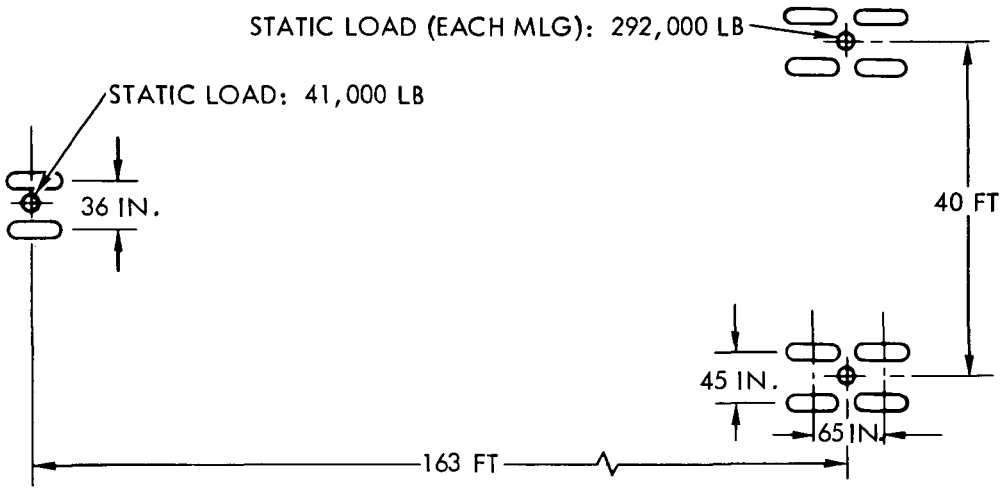
9. Roof loads of 20 pounds per square foot.

10. Wind loads of 125 miles per hour at a 30-foot elevation (per Wind Forces on Structures, Paper No. 3269, ASCE).

11. Acoustical subjection to 120 decibels from launchings at Pads 39A and 39B.

It is planned to construct a 25-foot by 350-foot enclosure along one wall to house activity managers, checkout personnel, a tool crib, subassembly repair areas, and mobile support equipment. The roof of this enclosure will be used to store slings, load bars, and tools (Figure 2-73).

Vehicle Storage. Protected storage of vehicle pending flight assignment is recommended. In the worst situation, all four boosters and five orbiters could be in storage. In that event, two boosters could be stored in the booster maintenance and checkout bay, two orbiters could be stored in the orbiter maintenance and checkout cells of the VAB, and a third orbiter could be stored in a third cell of the VAB.



CRITERIA:

1. TOTAL VEHICLE DRY WEIGHT = 626,500 LB
2. TIRE SIZE: NLG = 47 X 18 IN.
   MLG = 60 X 20 IN.
3. TIRE PRESSURE: NLG = 170 PSI
   MLG = 290 PSI

Figure 2-72. Booster Landing Gear Footprint Data and Loads

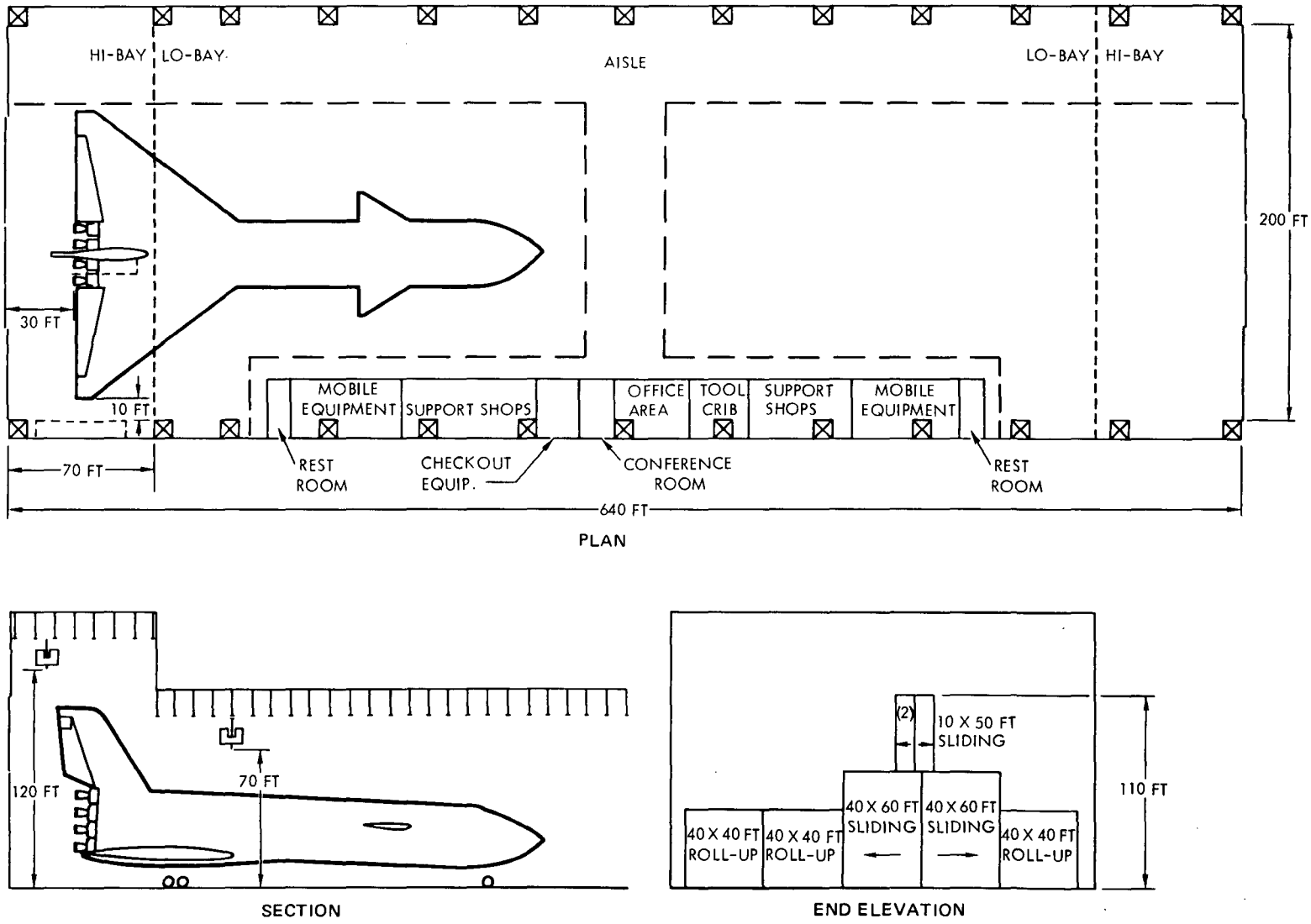


Figure 2-73. Booster Maintenance and Checkout Building

This arrangement leaves two boosters and two orbiters without storage provisions; therefore, it is proposed that a 280-foot by 640-foot storage addition be constructed adjacent to the booster maintenance and checkout bay to house these four vehicles. The building should be a minimum-cost structure since its only purpose is storage. Space between the vehicles may be used to store large repair tools, rocket engines (in cans), and similar items. The following criteria are applicable to this addition:

1. A total size of 280 feet by 640 feet.
2. A clear height of 110 feet.
3. Full-opening, motor-driven doors at the end of the booster storage bays and along the side of the orbiter storage bay.
4. Lighting to 25 foot-candles.
5. Mechanical ventilation.
6. Minimum electrical power and 90 psi filtered factory air.
7. No crane coverage (some localized jib booms or monorails may be required).
8. Concrete floors capable of bearing booster and orbiter wheel loads in the appropriate areas.
9. Roof, wind, and acoustical loads similar to those of the booster maintenance and checkout addition.

Taxi-Ways, Tow-Ways, Aprons and Roads

A vehicle taxi-way is required from the runway to the safing area. This taxi-way should be 125 feet wide with 40-foot shoulders on each side properly sloped for drainage. Taxi-way turn areas should be laid out to a 500-foot radius. Edge lights are required.

Vehicle tow-ways are required from the safing area to the VAB, past the safing area to the runway, and around the VAB. The tow-ways should be 75 feet wide with 25-foot shoulders on each side, properly sloped for drainage. Tow-way turn areas should be laid out to a 200-foot radius.

Paved aprons are required around the VAB and its new additions to allow movement of the vehicles from one location to another. These aprons

should be constructed to drain away from the VAB. Area lighting to 10 foot candles is recommended. Taxi-ways, tow-ways, and aprons should all be designed to booster wheel loadings. Automobile and truck roads at KSC will be 15 and 25 feet wide constructed to standard criteria, depending on the roads purpose.

Support Aircraft

Chase planes will be required to observe launches and to observe both vehicles as they approach the landing field and land. Extensive chase plane coverage is anticipated for early flights, diminishing as system confidence increases.

Weather observation planes will be required whenever potentially constraining weather occurs for either launches or landing.

Special Vehicles

Specially-outfitted vans will be required for transportation of crews and passengers to the launch pad, the safing area, major training facilities, or their quarters. Special vehicles also will be required for shuttle payloads of various sizes and contents, pyrotechnics, and various booster and orbiter supply items.

Aborts

Mission analysis indicates that aborted flights of the orbiter or the booster would land at United States military airfields. Facilitization of candidate airfields other than possible airstrip reconditioning, will not be accomplished in advance. After a landing, portable GSE and other servicing equipment will be air-ferried to the site; the vehicle then will be readied, checked out and flown back to the main operational base. In the event of vehicle damage, whether in the continental U.S. or overseas, other means may have to be used to return the vehicles to the main operational base. Possible recovery schemes include repair (e.g., landing gear, control surfaces, avionics, etc.) and flyout, towing to navigable water and barging out, partial dismantling and towing or trucking to navigable water, dismantling to sizes that can be flown out by Super Guppy, dismantling to allow trucking or rail transportation, and salvage. Specific requirements related to these recovery operations as well as locations of alternative fields are conjectural and do not warrant advance expenditure of funds.

Support Activities

The many support activities required at an operations site fall into five general categories:

1. Technical support, such as calibration services and standard physical, hydraulic, pneumatic, and electric laboratories.

2. Vehicle support, such as tubing, harness, valve, LO_2 cleaning and repair facilities.

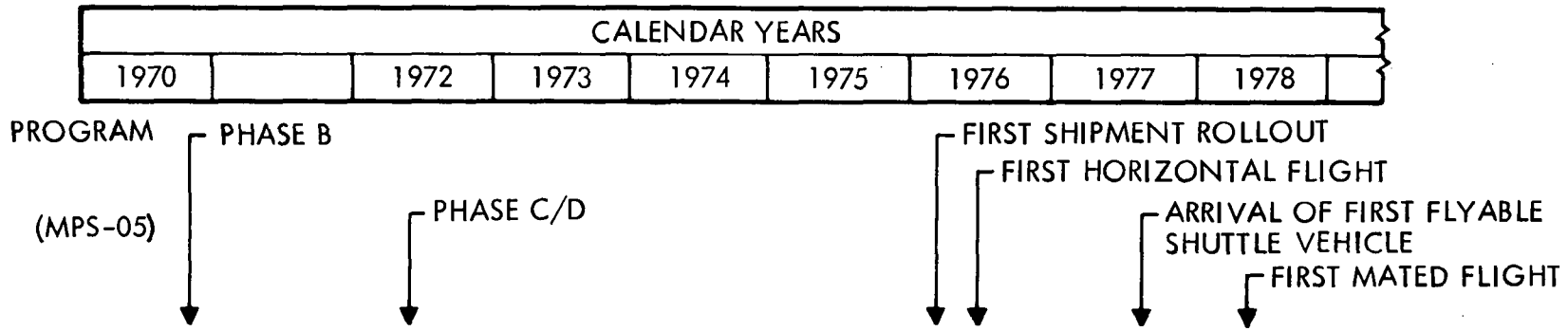
3. Maintenance activities for facilities, GSE, handling devices and slings, tooling, and the site and buildings.

4. General site services such as medical; fire protection; security; graphic reproduction; communications; data processing; and transportation of materials, components, and personnel.

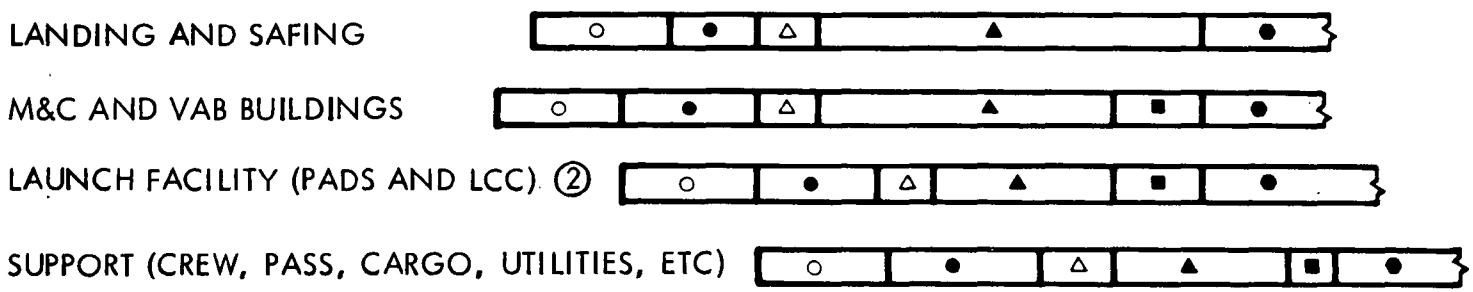
5. Office accommodations and equipment.

KSC has support activities in all these areas. No significant facility shortage has been identified, although some modifications will be required in certain areas. Office employees will be housed in the VAB where their task requires them to be in that area and in the office areas of the industrial complex at KSC.

Table 2-17 is a matrix listing the major facilities required at KSC. A schedule of implementation at KSC is given in Figure 2-74.



FACILITIZATION - LAUNCH OPERATIONS SITE (KSC) ①



NOTES:

① SCHEDULE COVERS FIRST PHASE ONLY. SOME ELEMENTS OF THESE ITEMS ARE DEFERRABLE UP TO ABOUT TWO YEARS

② DOES NOT INCLUDE MODIFICATION FOR STATIC FIRING CAPABILITY SEE SECTION 2.3.3

KEY:

- ○ PER'S AND A/E SELECTION
- ● DESIGN AND REVIEW/APPROVAL
- △ BID AND AWARD
- ▲ CONSTRUCTION
- ■ ACTIVATION AND EQUIPMENT INSTALLATION
- ● LAUNCH OPERATIONS

Figure 2-74. Implementation Schedule, KSC Major Facilities

Table 2-17. Major Facilities Required for Combined Booster and Orbiter Operations

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
OPERATIONS – KSC			
Manned spacecraft operations building. NASA. Available.	601, 748 ft^2; 252, 500 ft^2 office with remainder high bay and low bay for cargo operations and laboratories.	Modification required. $6, 000, 000 for demolition, partitions and payload sterilization.	Clean Area (100, 000 class) exists. Utilities satisfactory.
Central instrumentation facility. NASA. Available.	136, 400 ft^2: calibration laboratory, computer complex, telemetry station, data display and evaluation, antenna site.	No modification required.	Existing satisfactory.
Flight crew support and training building. NASA. Available.	65, 315 ft^2	Modification required, enlarge for passenger facility; $1, 800, 000.	Relocate utilities.
Environmental systems facility. NASA. Available.	10, 309 ft^2, 2 test cells and support rooms.	No major modification required.	Existing satisfactory.
Cryogenics Test Buildings 1 and 2. Fluid test support building. NASA. Available.	3, 600 ft^2. 11, 265 ft^2	No major modification required. No major modification required.	Existing satisfactory. Existing satisfactory.

Table 2-17. Major Facilities Required for Combined Booster and Orbiter Operations (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
Pyrotechnic building. NASA. Available.	18,000 ft^2	No modification required.	Existing satisfactory.
Spacecraft spares and equipment building. NASA. Available.	94,200 ft^2	No modification required.	Existing satisfactory.
Electromagnetic laboratory. NASA. Available.	9,486 ft^2 - checkout of antennae.	No modification required.	Existing satisfactory.
Communications and switching center. NASA. Available.	25,989 ft^2.	No major modification required.	Existing satisfactory.
Communications maintenance and storage facility. NASA. Available.	28,420 ft^2	No modification required.	Existing satisfactory.
Base support building. NASA. Available.	83,764 ft^2 - central shop for maintenance.	No modification required.	Existing satisfactory.

Table 2-17. Major Facilities Required for Combined Booster and Orbiter Operations (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
Spacecraft support buildings 1 and 2. NASA. Available.	13,000 ft^2 - hypergolic systems servicing and checkout.	No modification required.	Existing satisfactory.
Occupational health facility. NASA. Available.	14,334 ft^2 - dispensary.	No modification required.	Existing satisfactory.
Central supply. NASA. Available.	206,630 ft^2 - warehouse.	No modification required.	Existing satisfactory.
Headquarters building. NASA. Available.	439,446 ft^2 - administrative and technical offices.	No modification required.	Existing satisfactory.
News center. NASA. Available.	8,290 ft^2.	No modification required.	Existing satisfactory.
Vertical assembly building. NASA. Available with Saturn V sharing.	1,829,427 ft^2 - Maintenance and checkout, Booster final assembly, Storage of fleet.	Modify and enlarge by adding 620-by-520-ft with 110-foot chord. $28,000,000	Relocate secondary utilities in high and low bays.

Table 2-17. Major Facilities Required for Combined Booster and Orbiter Operations (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
Launch control center. NASA. Available with Saturn V sharing.	213,250 ft^2	Minor modifications. $200,000.	Relocate secondary power to support Shuttle Control Equipment.
Launch pads 39A and B. NASA. Available with Saturn V sharing.	20,000 ft^2, launch.	Modify/relocate electrical and control umbilical bases. $3,400,000.	Install closed loop water system.
Crawlerway. NASA. Available.	Two 40-foot wide roads from VAB to LC's 39A and B.	No modifications required.	Not applicable.
Barge terminal. NASA. Available.	Access canal and 1200 by 1200 ft turning basin.	No modifications required.	Existing satisfactory.
Industrial water facility. NASA. Available.	Supplies LC39 with industrial, firex and flame coolant water.	Modify to "closed-loop" System. $1,000,000.	Not applicable.
Launch equipment shop. NASA. Available.	28,200 ft^2.	No modifications required.	Existing satisfactory.

Table 2-17. Major Facilities Required for Combined Booster and Orbiter Operations (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
Taylor Creek UDOP and UDOD tracking stations. NASA. Available.	Launch tracking stations.	No modifications required.	Existing satisfactory.
Propellant laboratory and high pressure gas maintenance facility. NASA. Available.	35, 124 ft^2, clean rooms 135, 000 ft^2 paved area for tube trailers.	No modifications required.	Existing satisfactory.
Instrumentation facility. NASA. Available.	3, 044 ft^2 Control and monitor tracking equipment.	No modifications required.	Existing satisfactory.
Warehouse. NASA. Available.	500, 000 ft^2.	No modifications required.	Existing satisfactory.
Spacecraft building "AF". NASA/CKAFS. Available.	66, 170 ft^2 subassembly checkout.	No modifications required.	Existing satisfactory.

Table 2-17. Major Facilities Required for Combined Booster and Orbiter Operations (Cont)

Identification/Ownership/ Status	Description	Modifications/Cost	Special Facilities Equipment/Capability
ETR tracking stations. USAF/NASA. Available.	Merritt Island Cape Kennedy Patrick Air Force Base Range instrumentation ships Grand Bahamas Eleuthera Grand Turk Island Antigua Island Trinidad Ascension Island Others	No modifications required.	Existing satisfactory.
Merritt Island Airfield. New NASA Field.	10,000 - TT 600 - 300 ft wide, 2 miles northwest of VAB in LC 39 area.	New $20,600,000 - Field $ 6,000,000 - Safing	New (consider temporary use of CKAFS skid strip)
Port Canaveral. Civil. Available.	Marine support operations.	No modifications required.	Existing satisfactory.
Weather Forecast Facility. USAF/NASA. Available.	Cape Kennedy. Patrick Air Force Base.	No modifications required.	Existing satisfactory.
Heavy equipment maintenance. NASA. Available.	3,000 ft^2.	No modification required.	Existing satisfactory.

2.6 TRANSPORTATION

The Preliminary Transportation Plan identifies the mode of transportation, potential shipping and receiving points, and distances for the major assemblies in support of the Manufacturing, Development, and Flight Test Programs. Emphasis has been placed on reduced barging, handling, and transportation distances in the interest of cost and schedule to minimize damage potential. Many assembly and test alternates presently exist. The Transportation Plan supports the most feasible plan for each of the candidate final assembly sites at this time.

2.6.1 Manufacturing/Final Assembly (Transportation Support)

NASA Seal Beach/Downey

This plan provides tank and forward fuselage fabrication at Seal Beach. All other major structural assemblies/components are built elsewhere. The intermediate and aft fuselage assemblies are fabricated at other NR Divisions and are joined at Seal Beach with the crew module from Downey. Other major assemblies are "buy" items from other manufacturers.

The major assembly substructures are flown to the Long Beach Airport for trucking to Seal Beach (See Table 2-18) for mating and final assembly. The only barging requirement for manufacturing operations is for the completed vehicle from Seal Beach to Point Mugu, a distance of 65 miles, for flyout of the orbiter to the horizontal flight test site.

Michoud

This plan provides for LO_2 tank manufacturing at the final assembly site. Booster manufacturing and orbiter final assembly would require all the remaining Michoud area. This necessitates barging of all fuselage sections and wings. The crew module would be shipped by air transportation from Downey. Barging of the completed vehicle (See Table 2-19) to KSC (1190 miles) or to Eglin AFB (183 miles) would also be required. Barging to Elgin would require extensive modifications to waterways and unloading facilities. Barging the completed vehicle to KSC would require a dock on the ocean side of LC 39. The vehicle would then be flown to the horizontal flight test site.

Kennedy Spacecraft Center

As in the case of the Michoud plan, final assembly of the orbiter at KSC precludes other assembly effort at the facility because of space limitations. Booster final assembly, operations, NASA headquarters, and orbiter final assembly would require all the available area. This would

necessitate barging the major orbiter components (fuselage sections, wings, and tanks) See Table 2-20. The completed vehicle would be flown to horizontal flight test site.

Tulsa

The Tulsa plan provides for the manufacture of the intermediate fuselage on site. The aft fuselage would be built at Columbus and substructures flown to Tulsa for mating. The LH_2 tank/forward fuselage would be constructed at Seal Beach and barged to Tulsa. The crew compartment and LO_2 tanks would be built at Seal Beach, Downey, and air transported to Tulsa. Wing substructures would be air transported to the site. (See Table 2-21.) The completed vehicle would be flown to the horizontal flight test site directly from the final assembly site.

2.6.2 Development Testing (Transportation Support)

Transportation requirements to support the development test program normally requires a one-time shipment of a major test article to horizontal flight test, with the exception of completed vehicles. See Tables 2-18 through 2-21 for transportation detail by major site (Seal Beach, Michoud, KSC, Tulsa). Major test articles will be transported on fixtures (many of which were developed on previous programs) which permit roll on/roll off capability onto aircraft or barges.

Table 2-18. Transportation Plan, NASA, Seal Beach

Test Article	Test Description	From	To	Transportation Mode	Distance (Miles)
MANUFACTURING/FINAL ASSEMBLY					
Assembly LO_2 tank		NASA, Seal Beach	NR, Seal Beach	Dolly	At site
Forward fuselage and LH_2 tank		NASA, Seal Beach	NR, Seal Beach	Dolly	At site
Intermediate fuselage		Tulsa (substructures)	NR, Seal Beach	Fly, super guppy	1180
Aft fuselage		Columbus (substructures)	NR, Seal Beach	Fly, pregnant guppy	2010
Crew compartment		NASA, Downey	NR, Seal Beach	Truck	15
Wings		Buy item (substructures)	NR, Seal Beach	Fly, super guppy	
Vertical stabilizer		Buy item	NR, Seal Beach	Fly, mini guppy	
DEVELOPMENT TESTING					
Partial vehicle	Structure	NR, Seal Beach	MSFC	AKD and NASA barge, YFNB*	5222
Intermediate and aft fuselage	Acoustics	MSFC	MSC	NASA barge, YFNB	1628
LH_2, LO_2	Static fatigue	NASA, Seal Beach	Navy, Seal Beach Pneumo	Dolly	1
Crew Cabin	Acoustics	NASA, Downey	MSC	Fly, mini guppy	1388
Main LO_2 tank/ turbo compartment section	Thermal	NASA, Seal Beach	MSC	AKD and NASA barge, YFNB*	4000 406
OHMS tank compartment section	Thermal	NASA, Seal Beach	MSC	AKD and NASA barge YFNB*	4000 406
Main landing gear compartment section	Thermal	NASA, Seal Beach	MSC	AKD and NASA barge, YFNB*	4000 406
Forward landing gear compartment section	Thermal	NASA, Seal Beach	MSC	AKD and NASA barge, YFNB*	4000 406
Basic fuselage and thrust structure	Cluster firing	NASA, Seal Beach	KSC	AKD	4000 and return
OHMS, ACPS structures	Hot firing, integration	NASA, Seal Beach	WSTF	Truck	741
Power Generation system	Hot firing, integration tests	NASA, Seal Beach	WSTF	Truck	741
Crew cabin	Crew escape sled tests	NASA, Seal Beach	Holloman AFB	Truck	741
Flight test vehicle	Horizontal flight test	NASA, Seal Beach Point Mugu	Point Mugu Edwards AFB	Barge (modified) Fly	65 70

*Requires transloading at Michoud

Table 2-19. Transportation Plan, Michoud

Test Article	Test Description	From	To	Transportation Mode	Distance (Miles)
MANUFACTURING/FINAL ASSEMBLY					
Assembly LO_2 tank		Michoud	Michoud	Dolly	At site
Forward fuselage and LH_2 tank		NASA, Seal Beach	Michoud	AKD	4000
Intermediate fuselage		Tulsa	Michoud	NASA Barge, YFNB	875
Aft fuselage		Columbus (sub-structures) Tulsa (assembly)	Tulsa Michoud	Fly, pregnant guppy Barge	872 875
Crew compart-ment		NASA, Downey	Michoud	Fly, mini guppy	1661
Wings		Buy Item	Michoud	Barge, YFNB	
Vertical stabilizer		Buy item	Michoud	Barge, YFNB	
DEVELOPMENT TESTING					
Partial vehicle	Structure	Michoud	MSFC	NASA, YFNB	1222
Intermediate and aft fuselage	Acoustics	MSFC	MSC	NASA barge, YFNB	1628
LH_2, LO_2	Static fatigue	Michoud	MSFC	NASA barge, YFNB	1222
Crew cabin	Acoustics	NASA, Downey	MSC	Fly, mini guppy	1388
Main LO_2 tank/ turbo compart-ment section	Thermal	Michoud	MSC	NASA Barge, YFNB	406
OHMS tank compartment section	Thermal	Michoud	MSC	NASA barge, YFNB	406
Main landing gear compart-ment section	Thermal	Michoud	MSC	NASA barge, YFNB	406
Forward landing gear compart-ment section	Thermal	Michoud	MSC	NASA barge, YFNB	406
Basic fuselage and thrust structure	Cluster firing	Michoud	KSC	NASA barge, YFNB	1190 and return
OHMS, ACPS structures	Hot firing integration test	Michoud	WSTF	Truck	1146
Power gener-ation system	Hot firing integration test	Michoud	WSTF	Truck	1146
Crew cabin	Crew escape sled test	NASA, Downey	Holloman AFB	Truck	810
Flight test Vehicle	Horizontal Flight test	Michoud Michoud	KSC Elgin AFB (alt)	Barge, modified Barge, modified	1190 183

Table 2-20. Transportation Plan, KSC

Test Article	Test Description	From	To	Transportation Mode	Distance (Miles)
MANUFACTURING/FINAL ASSEMBLY					
Assembler LO_2 - LO_2 tank		Michoud	KSC	NASA barge, YFNB	1190
Forward fuselage and LH_2 tank		NASA, Seal Beach	KSC	AKD	4000
Intermediate fuselage		Tulsa	KSC	NASA barge, YFNB	2065
Aft fuselage		Columbus (sub-structures)	Tulsa	Air, pregnant guppy	872
		Tulsa (assembly)	KSC	NASA barge, YFNB	2065
Crew compartment		NASA, Downey	KSC	Fly, mini guppy	2352
Wings		Buy item	KSC	NASA barge, YFNB	
Vertical stabilizer		Buy item	KSC	NASA barge, YFNB	
DEVELOPMENT TESTING					
Partial vehicle	Structure	KSC	MSFC	NASA barge, YFNB	2465
Intermediate and aft fuselage	Acoustics	MSFC	MSC	NASA barge, YFNB	1628
LH_2, LO_2	Static, fatigue	KSC	MSFC	NASA barge, YFNB	2465
Crew cabin	Acoustics	NASA, Downey	MSC	Fly, mini guppy	1388
Main LO_2 tank/ turbo compartment section	Thermal	KSC	MSC	NASA barge, YFNB	1590
OHMS tank compartment section	Thermal	KSC	MSC	NASA barge, YFNB	1590
Main landing gear compartment section	Thermal	KSC	MSC	NASA barge, YFNB	1590
Forward landing gear compartment section	Thermal	KSC	MSC	NASA barge, YFNB	1590
Basic fuselage and thrust structure	Cluster firing	KSC	KSC	Dolly	At site
OHMS, ACPS structures	Hot firing integration test	KSC	WSTF	Truck	1723
Power generation system	Hot firing integration test	KSC	WSTF	Truck	1723
Crew cabin	Crew escape sled test	KSC	Holloman AFB	Truck	1655
Flight test Vehicle	Horizontal flight test	KSC	Elgin AFB	Fly	285

Table 2-21. Transportation Plan, Tulsa

Test Article	Test Description	From	To	Transportation Mode	Distance (Miles)
MANUFACTURING/FINAL ASSEMBLY					
Assembly LO_2 tank		NASA, Seal Beach	Tulsa	Fly, pregnant guppy	1180
Forward fuselage and LH_2 tank		NASA, Seal Beach	Tulsa	*Barge, AKD *NASA barge, YFNB	4000 875
Intermediate fuselage		Tulsa	Tulsa	Dolly	At site
Aft fuselage		Columbus (sub-structures)	Tulsa	Fly, pregnant guppy	872
Crew compart-ment		NASA, Downey	Tulsa	Fly, mini guppy	1180
Wings		Buy item (sub-structures)	Tulsa	Fly, super guppy	
Vertical stabilizer		Buy item (sub-structures)	Tulsa	Fly, mini guppy	
DEVELOPMENT TESTING					
Partial vehicle	Structure	Tulsa	MSFC	NASA barge, YFNB	1220
Intermediate and aft fuselage	Acoustics	MSFC	MSC	NASA barge, YFNB	1628
LH_2, LO_2	Static, fatigue	Tulsa	MSFC	NASA barge, YFNB	1220
Crew cabin	Acoustics	NASA, Downey	MSC	Fly, mini guppy	1388
Main LO_2 tank/ turbo compart-ment section	Thermal	Tulsa	MSC	NASA barge, YFNB	1278
OHMS tank compartment section	Thermal	Tulsa	MSC	NASA barge, YFNB	1275
Main landing gear compart-ment section	Thermal	Tulsa	MSC	NASA barge, YFNB	1275
Forward landing gear compart-ment section	Thermal	Tulsa	MSC	NASA barge, YFNB	1275
Basic fuselage and thrust structure	Cluster firing	Tulsa	KSC	NASA barge, YFNB	2065 and return
OHMS, ACPS structures	Hot firing integration test	Tulsa	WSTF	Truck	762
Power gener-ation system	Hot firing integration test	Tulsa	WSTF	Truck	762
Crew cabin	Crew escape sled test	Tulsa	Holloman AFB	Truck	693
Flight test vehicle	Horizontal flight test	Tulsa	Edwards AFB	Fly	1136

*Requires transloading at Michoud

2.7 PROGRAM MANAGEMENT AND SUPPORT FACILITIES

2.7.1 Site Evaluation Considerations

Facilities are required for all operations and activities that support development, manufacturing, and operation of the orbiter, but which are not accounted for in other sections of the Facilities Utilization Plan. Administrative and support facilities are required for the following functions:

1. Data processing.
2. Laboratories for quality control, engineering, and manufacturing development.
3. Material and logistics, including warehousing and shipping, and receiving.
4. Plant protection and medical services.
5. Plant and equipment maintenance.
6. Personnel and food services.
7. Reproduction and blueprint service.
8. Employment and training.
9. Program management and administration.
10. Engineering.

Areas required for program management and support functions are calculated in gross terms by applying a general square footage factor to each function and its estimated headcount. The resulting area requirements are depicted in Figure 2-75. The peak area requirement, which occurs in 1977, is then evaluated for each of the four candidate sites; i.e., Seal Beach and Downey, Tulsa, Michoud, and KSC. A comparison of the area requirement against the area available at these sites is given in Table 2-22.

2.7.2 Summary and Recommendations

The primary consideration involved in site selection for program management and support functions is the desirability of locating these functions at the final assembly site. The relationship between administrative, engineering, support, and final assembly operations is a vital factor in

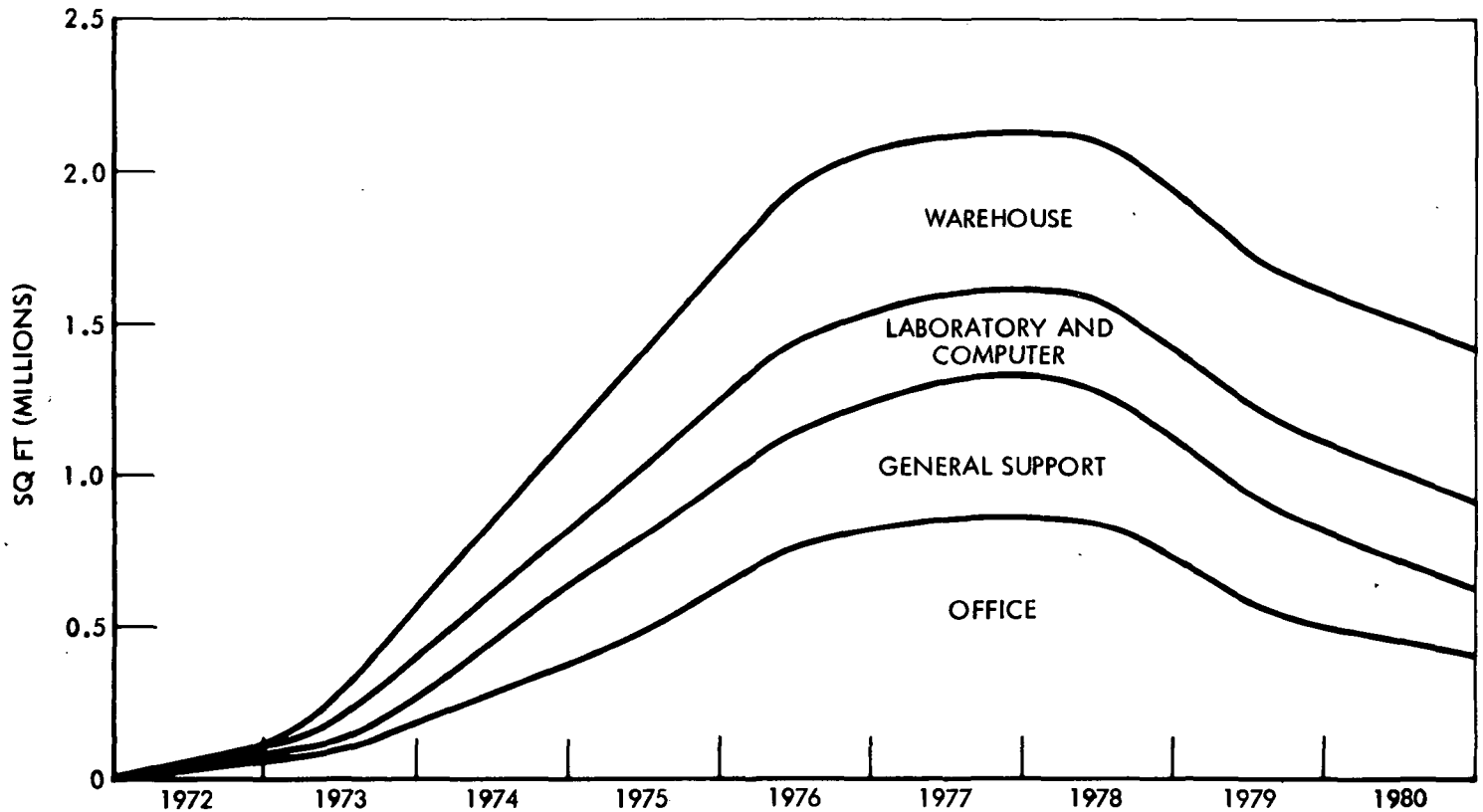


Figure 2-75. Program Management and Support Facilities Area Requirements

Table 2-22. Available Program Management and Support Facilities Areas

Support Activity	Projected Area Required*** (square feet)	Existing Area Available (square feet)			
		Seal Beach and Downey	Tulsa	Michoud	KSC
Engineering, administrative and office	830,000	830,000	122,600	834,790	746,012
Material and logistics including warehousing, shipping and receiving	500,000	438,000	246,000	333,000	500,000
Data processing	50,000	50,000	5,000	103,000 (Slidell Facility)	9,030
Quality control and engineering laboratories	250,000	250,000	86,000	636,361	61,764
General support	283,000	283,000	50,000	**	**
Facility maintenance	85,000	85,000	37,000	16,000	8,360
Personnel and food services	30,000	30,000	14,200	35,000	**
Plant Protection and Medical	25,000	25,000	4,500		42,864
Reproduction and blueprint service	30,000	30,000	7,800	84,000 Contractor support	15,200
Employment and training	30,000	30,000	1,500		(4,800) (Contractor) (support)
Total administrative and support	2,113,000	2,051,000*	574,000	2,042,151	1,388,030

*Total area Seal Beach and Downey, 3,500,000 square feet
**Exists, total area unknown.
***Peak requirement 1977.

successful aerospace program management. Liaison and support are required for all subassembly and detail fabrication activities and for all development testing aspects of the program, but the relationship with final assembly is of critical importance.

With Seal Beach as the final assembly site, the North American Rockwell administrative and engineering base at Downey and Seal Beach provides the necessary administrative and support activities and areas as well as the necessary geographical proximity. These activities and areas are presently established and operational today, and only normal rearrangements and relocations would be required for activation (Figures 2-76 and 2-77). This advantageous arrangement minimizes costs relative to equipment and personnel relocations, hiring and training, and facility modification or construction. Delays and lost time after contract go-ahead also would be minimized and would enhance program scheduling. The program also will benefit from the intangible advantages of maintaining an existing organization intact, including personnel, operating procedures, and established liaison.

Tulsa provides the benefits of established operations and organization. Operating procedures, an engineering base, and established liaison procedures exist. To maintain program continuity, some reorganization would be required as well as relocation of some personnel from Downey.

Selection of KSC or Michoud for final assembly requires the establishment of a new organization structure as well as operating and liaison procedures by NR. Since North American Rockwell presently does not occupy the sites (other than a small scale activity at KSC), a larger number of personnel would have to be relocated. Reviewing Table 2-22, Michoud provides a much larger general support capability, however, than Tulsa or KSC.

The primary recommendation is that the administrative, support, and engineering functions be established at the final assembly site. Downey and Seal Beach provide the major requirements and advantages for the subject activity.

The Downey and Seal Beach sites are presently established with the necessary facilities, procedures, operations, and organization.

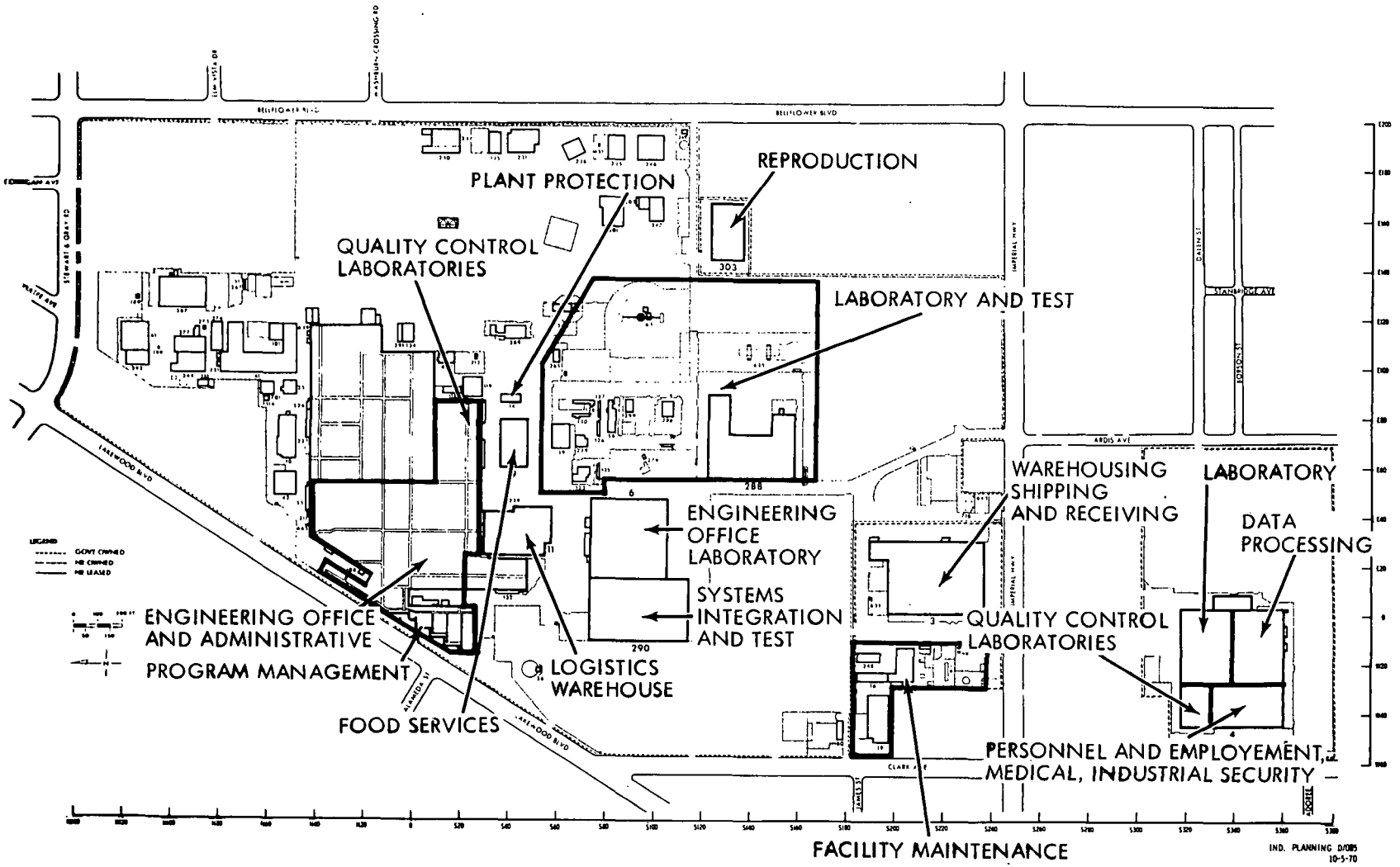


Figure 2-76. Downey Program Management and Support Activities

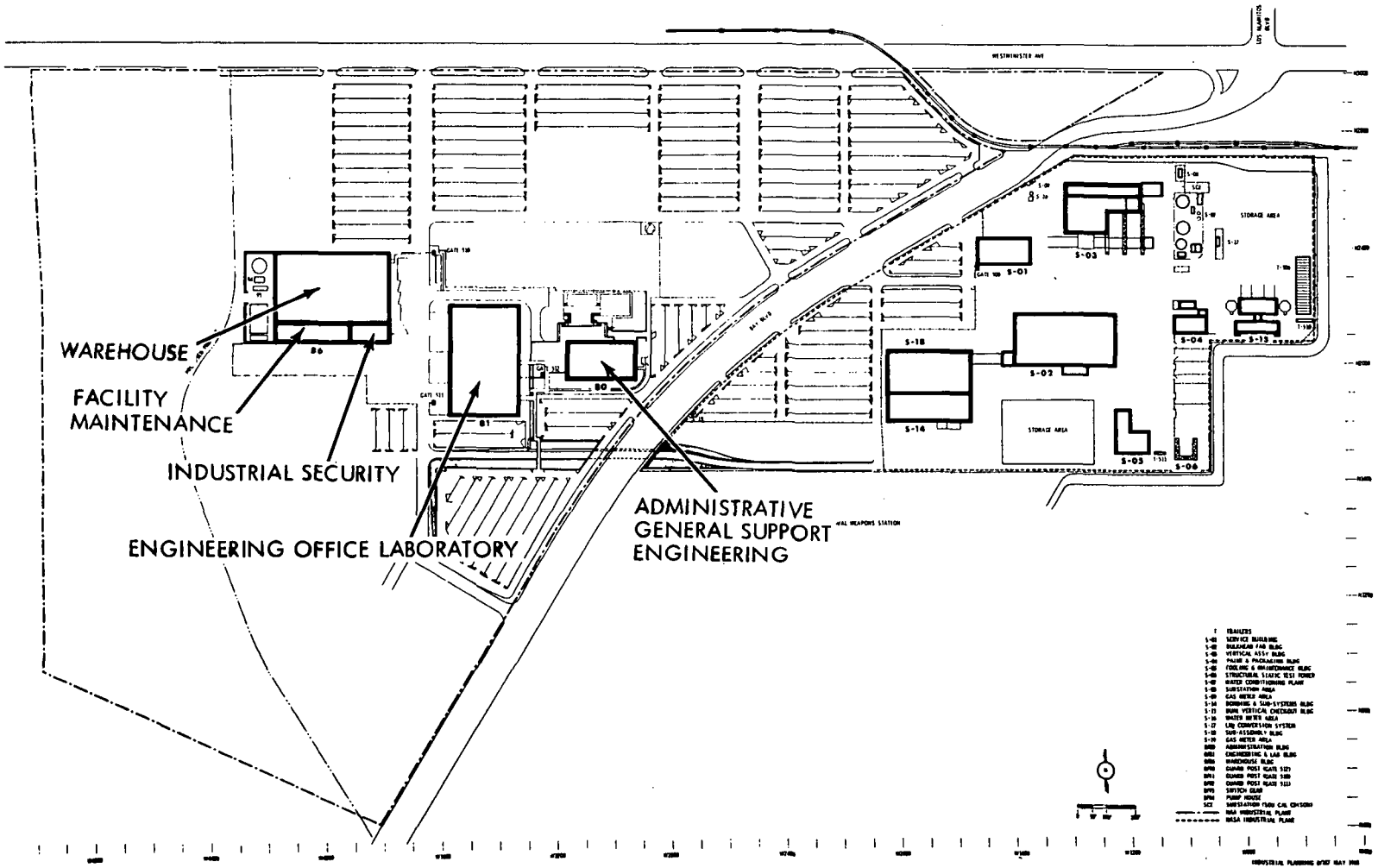


Figure 2-77. Seal Beach Program Management and Support Activities

2.8 ORBITER TRAINING FACILITIES

Facilities required for the orbiter training program include classrooms, shop areas, and training equipment. The training program will be conducted for both NASA and contractor personnel engaged in orbiter manufacturing, development, testing, operations, and maintenance activities.

Adequate training area is available at each candidate site considered for final assembly, major assembly, horizontal flight testing, and operations. Classrooms, conference rooms, and assembly rooms are included in the office and administrative areas described in Section 2.6 of this document. At Downey and Seal Beach, complete training facilities established during the Apollo and Saturn programs are directly applicable to the Shuttle Program. Similarly, existing training facilities at Tulsa, Michoud, and KSC are suitable for Shuttle Program needs.

A major element of the training program is the training of NASA and contractor personnel in vehicle maintenance. Facilities at the American Airlines modification and overhaul center at Tulsa and at the American Airlines facility at the Los Angeles airport are ideally suited to orbiter maintenance training. Furthermore, these installations are staffed with experienced training personnel who will employ established training methods and procedures.

Training for Shuttle Program operations will be accomplished at the operations site with appropriate support from the horizontal flight test site. Facilities developed at KSC for on-going space programs provide core training capability including flight simulation and computer support. At both KSC and Edwards Air Force Base, complete astronaut training complexes have been established.

Equipment required for training includes training devices, graphics, projection and display equipment, specialized training aids, and equipment of the following general types:

1. Flight mission simulator to develop skills and proficiency in shuttle missions and systems operation.

2. Procedures trainer with cockpit interior for cockpit familiarization.

3. Maintenance trainers for specific elements of the orbiter on which maintenance tasks requiring critical skills or high proficiency may be performed.

4. Egress trainer mockups permitting both flight crews and passengers to practice ingress and egress through the airlock or payload module to the space station docking hatch. Ingress and egress from the horizontal and vertical vehicle position for normal and emergency transfer should also be possible.

5. A passenger trainer to provide passenger orientation with the vehicle interior and operation of the life support systems.

6. A docking simulator to practice payload module docking with the space station and with other space objects for satellite retrieval and inspection.

7. Other devices and trainers include emergency trainers, ditching procedures trainers, and onboard training equipment for on-orbit training.

Equipment provided to meet manufacturing, development, and testing training requirements will be utilized on a shared basis, whenever possible, to avoid duplication of equipment requirements.

The use of trainers and devices from other programs, modified as required, will be maximized to implement a training program in the most cost effective manner.

3.0 MANUFACTURING TECHNOLOGY

3.0 MANUFACTURING TECHNOLOGY

To establish appropriate perspective of the total orbiter manufacturing task, manufacturability trade studies were conducted and requirements for design, development, and manufacturing were evaluated during Phase B. Results of these studies were applied by Manufacturing to develop a detailed plan containing sequential flows for tooling, fabrication, assembly, system installation, checkout, and inspection. The task analyses performed have revealed that most of the manufacturing technology required to fabricate the vehicle is understood and that certain items identified as problems and concerns represent but a small percentage of the total task and involve primarily the approaches to planned manufacturing techniques. A summary of the product task complexity associated with each major orbiter assembly is given in Table 3-1. The assemblies noted may be identified in the manufacturing breakdown (Figure 3-1).

The following three sections contain discussions of "Major Manufacturing Problems," "Manufacturing Concerns," and "Items Causing Substantial Program Impact." Items identified as major manufacturing problems are those capable of substantial program impact. Manufacturing concerns are limited to areas involving significant manufacturing complexity, but not threatening general program impact.

3.1 MAJOR MANUFACTURING PROBLEMS

3.1.1 Reusable External Insulation (REI) - Nonmetallic

Because of its relatively recent development status and the lack of pertinent detailed manufacturing processing procedures and standards, the use of rigidized silica or mullite fibrous panels for reusable external insulation may present several major problems. It is currently planned that the development of materials and the fabrication of REI detailed panels will be performed by a major material supplier and that NR Manufacturing will bond the REI to substrate metallic panels and install the completed panels on the vehicle.

Due to the properties of REI material, it is anticipated that repair of handling damage will be required. To date, repair methods for these materials have not been developed. The same conditions are applicable to the external hard coating used for thermal control and moisture resistance.

Table 3-1. Manufacturing Task Analysis

Task	Assembly																
	Nose Cone	Nose Assembly	Forward Fuselage	Integral LH_2 Tank	Crew Module	Intermediate Fuselage	Main LO_2 Tanks	Aft Fuselage	OMS/ACPS Integrated LO_2 Tanks	Wing Assembly	Vertical Stabilizer	Payload Bay Doors	Air Breathing Engine Assembly	Thermal Protection System	Reusable External Insulation (REI)	Carbon/Carbon Composites	Reradiative Panels	Ablative
Fabrication	S	S	S	C	S	S	S	S	S	S	S	S	S		P	S	C	C
Processing	S	S	S	C	S	S	S	S	S	S	S	S	S		P	P	C	S
Assembly	S	S	S	C	C	S	S	S	S	C	S	S	S		P	S	S	S
Installations	S	S	S	S	S	S	S	S	S	S	S	S	S		P	S	S	S
Checkout	S	S	S	S	S	S	S	S	S	S	S	S	S		NA	NA	NA	NA
Handling	S	S	S	C	S	S	S	S	S	S	S	S	S		C	C	C	S
Transportation	S	S	S	C	S	S	S	S	S	S	S	S	S		C	S	S	S
Inspection	S	S	S	C	S	S	S	S	S	S	S	S	S		C	C	S	S

Key: S = State of the art P = Problem
C = Concern NA = Not applicable

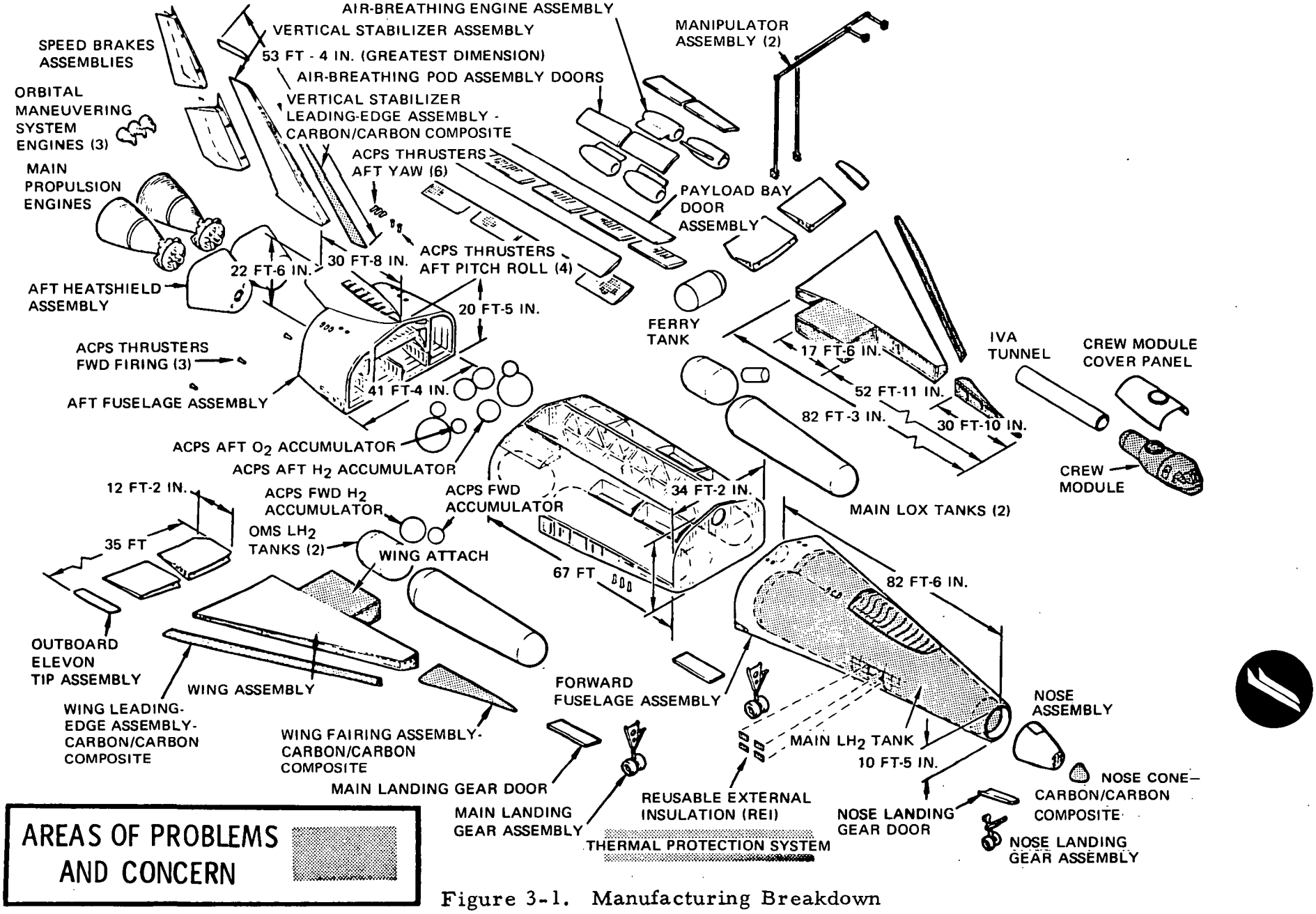


Figure 3-1. Manufacturing Breakdown

In bonding REI to the metallic substrate panels, problems are expected in dimensional coordination and control of bond-line thickness to assure aerodynamically smooth external surfaces. Other problems will be encountered devising methods for sealing gaps and openings in the REI against moisture while allowing for air venting and thermal expansion differentials.

Technical Approach to Solutions

General approaches taken to resolve problems in the fabrication, assembly, and installation of REI panels are the following:

1. Maintaining liaison with designers, materials engineers, and materials suppliers involved in the development of REI.

2. Conducting REI material and fabrication methods studies, trade studies, developmental tests, and reviews of progress by other companies performing related programs under NASA contracts.

3. Contracting with material producers to develop specific solutions to basic material problems, such as repair of damaged coatings and secondary bonding procedures.

4. Disseminating and exchanging REI development information among the customer, suppliers, and NR personnel.

5. Establishing training programs for production personnel in the proper handling, fabrication, and installation of REI panels.

6. Developing inspection techniques to assure proper bonding, sealing, and dimensional characteristics in compliance with the provisions and requirements delineated in Appendix E of the Program Management Plan - Quality Program Plan.

New Technology Requirements

The basic processes employed in the manufacture of REI consist of cleaning the surfaces of small-diameter fibers (e. g., quartz), impregnating with a rigidizer (e. g., silicone), molding, heat treating in air to rigidize, machining to dimensions, and applying thin surface coatings. The low mechanical strength and high potential for water absorption resulting from the high porosity necessary to meet weight and thermal conductivity requirements make the protective coating mandatory. The mechanical and physical requirements imposed upon this coating are severe and will be difficult to meet. A presently used moisture-barrier silica-based coating, which is applied as a slurry and fused at high temperatures, will require reinforcement to meet orbiter requirements.

Room-temperature-vulcanizing (RTV) silicones develop adequate strength for adhesive bonding of the insulation panels to the substrate structure. Silicones are available for use at temperatures up to 655 F. The allowable bond line is approximately 0.05 inch, which will be difficult to control since no forward steps are permissible in the REI aerodynamic surfaces. Because the bonding material can contribute significantly to the overall weight of the vehicle, methods must be found for reducing the quantity of bonding material; e.g., foaming or using a discontinuous bond.

The effects of gaps between adjacent panels is being studied and evaluated. A 0.030-inch gap perpendicular to the gas flow may be acceptable, but longitudinal gaps will require sealing. Gap sealing techniques employing either woven gasketing material or ceramic cements are being investigated. The method selected must allow for sufficient panel expansion during heating without creating compressive edge loads on the REI sufficient to cause failure.

The relatively low strength and poor impact resistance of REI also necessitates methods for prevention of handling damage; therefore various types of shock-resistant packaging and handling equipment are being defined and evaluated. Procedures must be developed for assembly and installation of the fragile REI panels to avoid creation of surface irregularities, preserve aerodynamic smoothness, maintain adhesive bond reliability, and ensure sealing integrity.

In addition, because REI is highly susceptible to damage, simple and effective methods of repair are required. Repair studies indicate that coring and plugging may be the most efficient repair method; however, further evaluation on full-size contoured panels is necessary.

3.1.2 Carbon/Carbon Composites

The primary problem to be solved in constructing leading edges of carbon/carbon composites is the development of a reusable oxidation and erosion resistant coating. Furthermore, maintenance of such coatings in reusable condition will require damage-protection measures and repair procedures presently considered to be problematical.

Technical Approach to Solutions

The proposed solution to attain oxidation protection for carbon/carbon composites is the incorporation of additives (e.g., zirconium, zirconium dioxide, and silicon) into the composite during fabrication and the diffusion of silicon into the surface to form silicon carbide. Proper protection in handling coated composite parts may be accomplished by means of special

shock-resistant packaging and personnel trained in the use of this new material. Damage prevention is of primary importance because of the difficulty of repairing a damaged carbon/carbon composite part without refiring at a special facility. Close liaison is being maintained with Ling-Temco-Vought, who is currently under NASA contract to develop carbon/carbon composite components.

State of the Art

The state of the art in fabrication of carbon/carbon composites is relatively well advanced. Suppliers can provide basic materials possessing a wide range of capabilities and can process these materials into finished shapes, but not in the large sizes required for the shuttle. Since a truly oxidation-resistant carbonaceous composite has not been developed, the only valid approach applicable to the space shuttle is the use of an oxidation-resistant silicone coating for which processing methods and equipment must be devised.

Reinforcement materials for use with pyrolyzed plastics are being selected from the high-strength carbon and graphite cloths currently available; the resins to be used are being selected from the available phenolic and furfuryl resins. Layup and curing of the composites can be accomplished by methods similar to those currently used. The resins are converted to carbon by pyrolysis in an inert atmosphere at a temperature of about 1800 F. Subsequent graphitization at 4500 F can be used to stabilize the structure if temperatures higher than those now expected are to be encountered.

Dimensional changes during pyrolysis are anticipated; nevertheless, fabrication to close tolerances is considered feasible. Finishing operations can be accomplished without difficulty by conventional techniques, but are time consuming. Successive reimpregnation with resin and repyrolysis will be used to increase density and strength as necessary.

New Technology Requirements

Although the preceding approaches are based on state-of-the-art fabrication techniques for small testable specimens of flat or curved configurations, it should be noted that components scaled up to shuttle size will require improved technology and processing facilities larger than those now available. Should repair of installed carbon/carbon composite panels be required in the field, a transportable high-heat facility will have to be developed, tested, and certified. Several such concepts are being evaluated.

Vapor deposition of silicon into the slightly porous carbon/carbon composite structures and concurrent heat treatment to convert the silicon to carbide will be used to provide oxidation inhibition. In the last stages of the vapor deposition, methane will be added to the vapor-plating atmosphere to provide an overlay coating of silicon carbide for additional oxidation and erosion protection.

To preclude damage to these materials in the finished state cost-effective protective handling techniques will be developed for transfer of completed panels of various configurations from the processing facility to the installation site.

Quality assurance nondestructive evaluation (NDE) techniques will be used, and adequate process controls will be defined to assure maximum product reliability and compliance with the provisions and requirements delineated in Appendix E of the Program Management Plan - Quality Assurance Program.

3.2 MANUFACTURING CONCERNS

3.2.1 Main LH_2 Tank

The integral tank imposes a critical production schedule that is of concern during fabrication, assembly, cleaning processes, handling, and transportation. Manufacturing flow requires that the task phases be incorporated into a scheduled span to support manufacture of the vehicle. For example, the tank completion date bears a direct relationship to the in-work date of the forward fuselage buildup and subsequent operations.

The tank design consists of a welded shell which is integrally stiffened by sculpturing and contouring, and a mechanically jointed structure installed along the centerline. (Figure 3-2). It serves a part of the vehicle's primary load carrying structure and is a basic element of the forward fuselage assembly.

The tank configuration consists of conical half shells jointed along the X-axis centerline. The forward and aft bulkheads are siamesed elliposiodal shapes. Overall length is 76 feet. The forward bulkhead is 14 feet in diameter along the Y axis, and the aft bulkhead is 31 feet in diameter along the Y axis.

Conventionally fabricated structures are bolted to the integral tank flanges at the forward and aft bulkheads and do not involve any new technology other than resolution of tooling requirements and installation in the forward fuselage assembly tool.

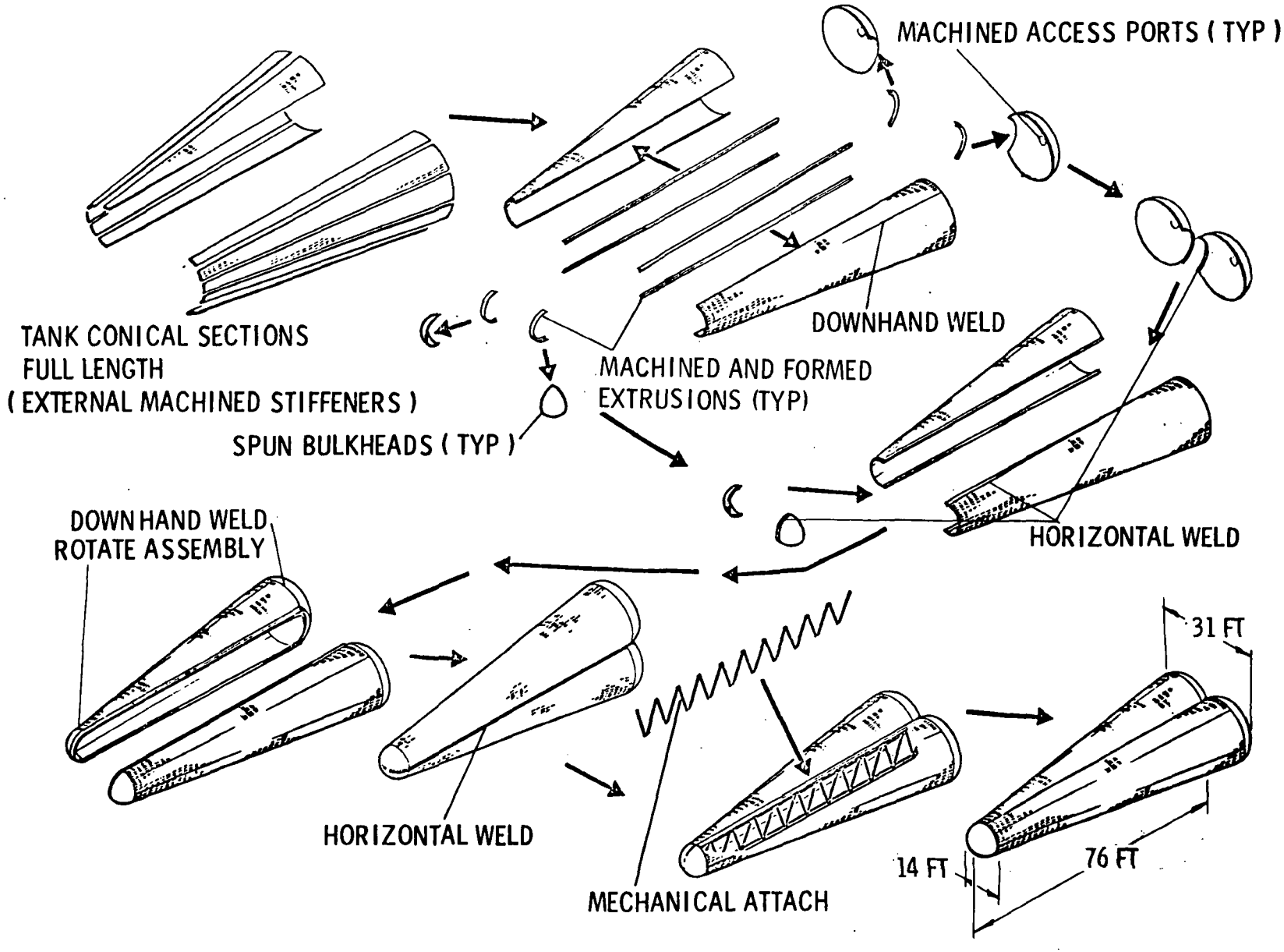


Figure 3-2. Manufacturing Assembly and Weld Sequence, Main LH_2 Tank

Solutions

Technology required in fabricating the tank involved a detailed study of the materials and configuration. The skin and bulkhead panels are 2219 T87 aluminum alloy of various thicknesses. The membrane sections range in thickness from 0.050 to 0.110 inch and are reinforced with a sculptured waffle-type grid pattern 10 x 20 x 0.750 inches. The grid is on the exterior of the panels to provide structural stiffness, frame attachment flanges, and a smooth interior surface for the application of insulation.

During the trade studies of assembly breakdown, tooling, and welding processes and equipment, criteria for manufacturability were established. These criteria were in part substantiated by a supplier survey and a Material Division request for quotation involving the production of large aluminum sheet with present mill capability. Alcoa responded with a capability of supplying a maximum size plate 1-1/2 inches thick, 12 feet wide and 80 feet long and weighing 29,000 pounds. These dimensions enabled Manufacturing Engineering and Design Engineering to establish a vehicle baseline manufacturing plan with fabrication and assembly of the tank from large skin panels of 1-1/2 inches x 9 feet x 68 feet. This use of large panels eliminates the requirement for circumferential skin-panel joining employed on the Saturn II vehicle. Circumferential weld joints would have increased orbiter costs and reduced total weld reliability. In addition, the costs of joining fitup tooling for circumferential welding, and the associated nondestructive testing requirements are reduced.

Forming and Machining

Fabrication of the bulkhead and skin panels of these tanks will be accomplished with conventional techniques that are already proven in the manufacture of the Saturn vehicle. North American Rockwell has thoroughly demonstrated its capabilities for machining large parts; therefore, it is planned that the skin panels be machined from flat, full-length (approximately 70-foot) stock in the T37 condition. The machined panels will then be drape-formed and aged to acquire the desired properties (T87). Again except for sizes and configurations of the parts, the drape-forming and aging processes are proven techniques; however, trade studies are in progress, and full-scale test parts will be fabricated to duplicate the conditions for verification. NR studies also indicate this approach to be the most cost effective. On the basis of NR experience in fabrication of the S-II cylindrical quarter panels, the conical skin panels nevertheless could be made of several smaller panels as an alternative approach using current technology, but requiring additional circumferential welding.

Bulkheads, because of their large sizes, have often been fabricated of gore sections and welded. Although this technique has been proven to be satisfactory, fabrication has been costly. Investigations, through trade studies, are being made of the various fabrication methods, and evaluations are being conducted to determine costs, and end-product confidence levels. Results of these studies indicate that the spinning technique is the most attractive from a cost standpoint. The maximum size of these bulkheads is within the capabilities of available equipment. For those bulkheads requiring access doors, the thickness of the spun bulkhead will be adequate to permit chemical and conventional machining of the access door opening.

It is anticipated that T42 material be procured, welded into the spin-blank, solution treated, spun, aged to (T62), and then machined. An alternative to this method includes spinning from thinner material and dollar welding of door and feedline flanges. The present spinning capability for the forward bulkhead is proven by experience, and the aft bulkhead spinning capability requires resizing of the equipment. In the event that spinning contractors do not resize to Shuttle Program requirements, the Saturn II gore forming and welding methods will be implemented and applied to the aft bulkhead.

Welding State of the Art

It is recognized that total system design is a prerequisite to establishment of the production welding program. Sequential integration of all operations and their individual detailed procedures will be provided for the Space Shuttle Program. Welding technology developed on the B-70, Apollo, and Saturn Programs, in conjunction with the latest advanced techniques and processes, will be applied to the Space Shuttle orbiter.

A study was conducted on the welding problems involved in the orbiter fabrication. This study resulted in the recommendation of practices and procedures that will assure quality welding at minimum cost. Included in these recommendations are weld positions, weld processes, and tooling concepts for welding and for inspection of weld joints and preweld and post-weld procedures.

Welding Processes

Seven machine-welding processes were evaluated for practical application on the orbiter. The evaluation was based on tanks of all 2219 T87 aluminum alloy construction with particular consideration of their sizes and complexity. Two proven NR processes were selected: direct-current

gas-tungsten arc (DC/GTA), and pulsed direct-current gas-tungsten arc. Welding equipment used on the Apollo and Saturn Programs is fully compatible with the selected processes and is available for use on the Shuttle Program at a considerable cost savings. Next in order of preference is electron beam welding, which also has been proven at NR on smaller assemblies.

Weld Positions

An evaluation of all possible weld positions was performed to establish an order of preference based on quality of weld achieved, tooling cost, and production time and cost. The evaluation revealed downhand and downhand-modified methods to be preferable. Welding in these positions simplifies both welding and material handling problems.

It is recognized that all positions evaluated can be performed without the use of costly chill tooling (free-fall welding) when employing the direct-current gas-tungsten-arc (DC/GTA) or pulsed, direct-current gas-tungsten-arc processes; however, these processes do compromise weld quality. It is often necessary to tool for welding the parts in positions other than downhand because of their size and complexity. Tooling and weld schedules become significant factors in these instances. Examples of this approach are the welding of the extrusion-to-cone section of the main LH_2 tank and the final closeout weld of the main LH_2 tank.

Weld Tooling

All portable skate-welding equipment and floor-mounted weld tools will be designed for welding in the downhand position wherever feasible and economical. Tools will not be designed for an out-of-position welding technique unless approved by a manufacturing welding engineer. Weld joints on large assemblies will be radiographed with portable X-ray equipment while the assembly is in the tool. Appropriate mounting provisions for the X-ray equipment will be provided. The portability of this inspection equipment allows weld repairing without removal of the assembly from the tool.

Assemblies that must be welded from the mold-line side will require prepeaking of the joint to maintain postweld configuration control. This provision will be designed into the weld tools. All tooling material adjacent to the weld joint will be nonmagnetic to prevent interference with the welding arc.

Skate-weld tooling, which is generally less costly than floor-mounted tooling, will be used wherever practical.

Preweld trim and joint preparation capabilities will be designed into all tools wherever applicable.

Free-fall weld tooling will be designed for aluminum in thicknesses of 0.060 to 0.500 inch with access provided on the drop-through side for infrared sensing, closed circuit TV, or visual penetration control methods. Aluminum thicknesses of 0.020 to 0.060 inch will require stainless steel chill tooling rather than copper. Stainless steel is not only cheaper, but has better chill uniformity characteristics than copper. Air-actuated clamps similar to those used on the Apollo/Saturn Programs will be used in conjunction with chill tooling where required.

Joint Design

Reinforced weld lands to aid in fit-up and lowered postweld requirements are recommended to Design Engineering. To minimize joint preparation costs and maximize subsequent weld quality, square butt joints are recommended for all the orbiter tanks. The automatic machine welding process is recommended for all weld repairs to assure uniform weld quality.

Inspection

Unless otherwise directed by engineering technical requirements, the minimum nondestructive testing requirements for welded assemblies will require visual, fluorescent penetrant, and radiographic inspections. Large assemblies will be tested in the welding fixtures, while smaller assemblies will be tested in the inspection laboratory. Access will be provided, as required, to both surfaces of the weld for the visual, penetrant, and X-ray inspections in coordination with Manufacturing tooling and fabrication personnel. Minimum dimensional requirements to accommodate X-ray equipment are shown in Figure 3-3. This inspection will comply with the provisions and requirements delineated in Appendix E of the Program Management Plan - Quality Assurance Program.

Tank and Component Handling and Transportation

Handling and transporting systems as well as equipment requirements were developed on the basis of experience gained in the Apollo and Saturn II Programs (Figures 3-4 and 3-5). Extensive use of valu-lifts; padded contour boards mounted on pallet bases; and handling fixtures adapted to transporting, lifting, and positioning are used for flat and contoured skin panels and bulkhead sections. Unique requirements and new handling technology are not required, except for designing equipment and fixtures to accommodate orbiter component dimensions.

The complete tank handling transportation system is based on Saturn II handling and transportation technology. The plan includes the same facilities, equipment, and techniques for transporting and handling of the tank throughout the assembly, test, insulation, in-tank subsystem installations, and

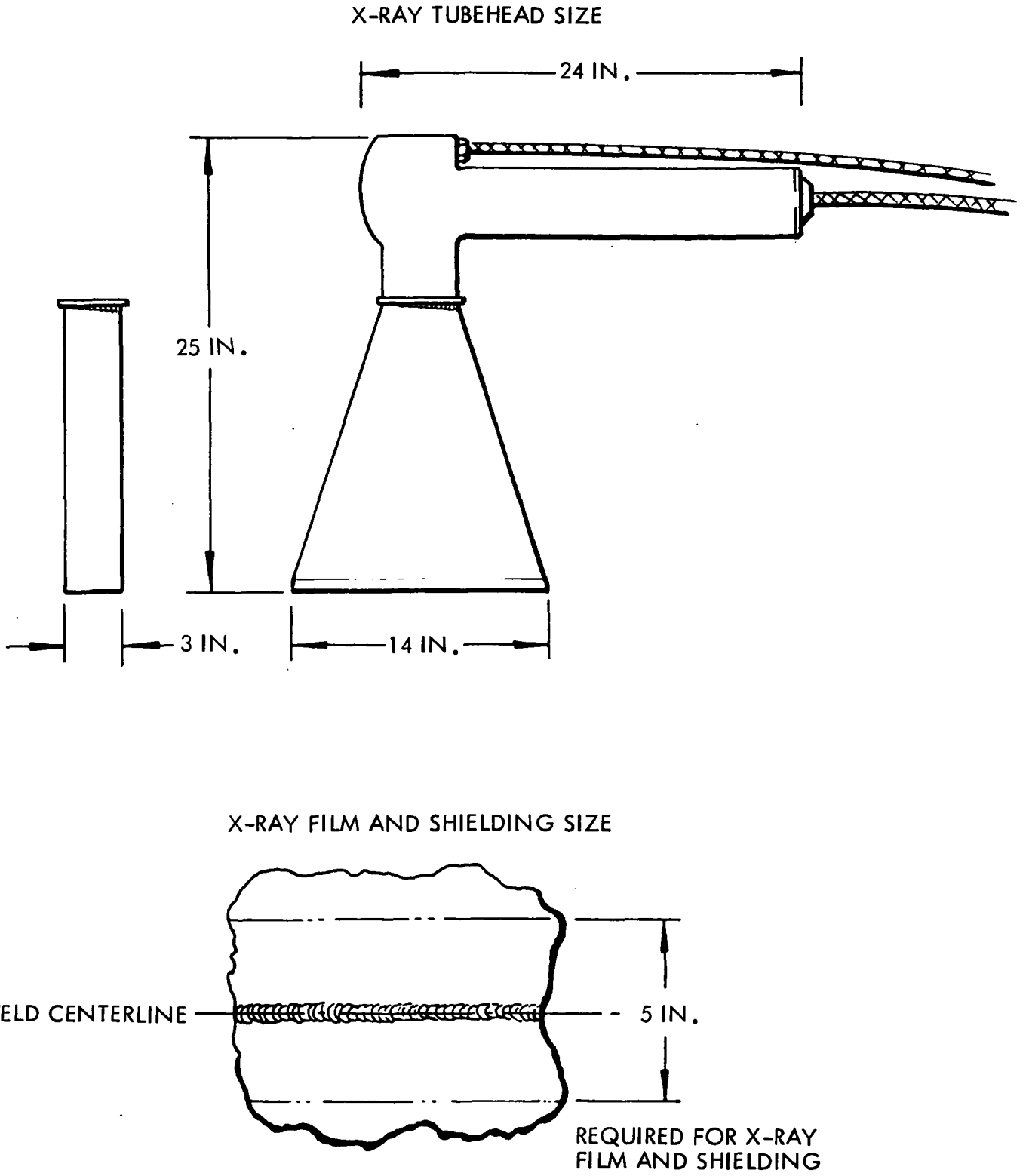


Figure 3-3. Dimensional Requirements to Accommodate X-Ray Equipment

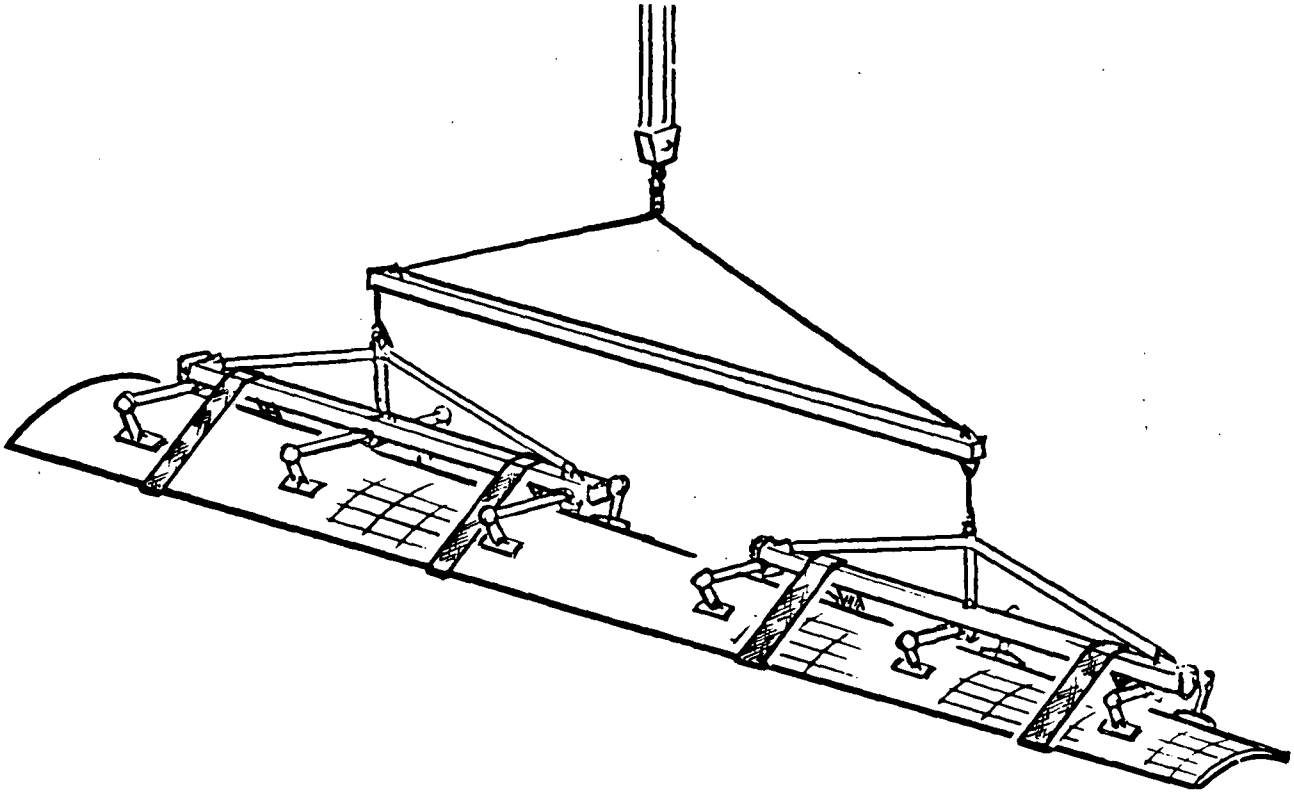


Figure 3-4. 80-Foot Panel Handling

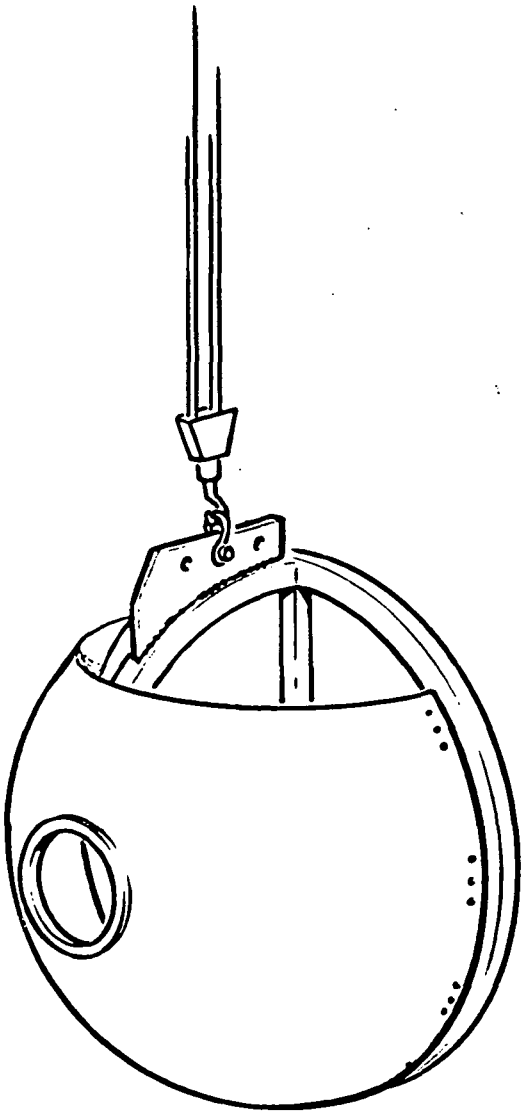


Figure 3-5. Bulkhead Handling

inspection processes. The S-II booster transporter (Figure 3-6) will be used. Although no new technology is required, some modification of the equipment is required: the attachments and rotational gear must be sized to the orbiter tank dimensions; and the inerting, pressurization, and monitoring systems must be changed to comply with the tank requirements.

The transporter will be used for moving the tank to a test site and also to the cleaning station (Figure 3-7). Rotation of the tank from the horizontal to the vertical position for cleaning requires systems and equipment similar to that used for the S-II vehicle.

3.2.2 Half-Scale LH_2 Test Tank

Concurrently with the technical evaluation of the main LH_2 tank, Manufacturing established a plan for fabrication and assembly of a one-half-scale double-conical LH_2 test tank (Figure 3-8). Experience gained in fabrication and assembly of the test tank will be applied to the construction of the full-sized orbiter tanks.

The test tank assembly of 2219T aluminum is approximately 18 feet long and 14 feet wide with a box beam joint. Fabrication techniques for the components have been determined, and methods for sculpturing the large skins with external stiffeners and forming the contour by means of a hot drape form fixture have been defined in the build plan (Figures 3-8 and 3-9).

The dome-shaped end bulkheads will be spun, heat treated, sized by a second spin operation, and subsequently heat-aged, prior to Chem-Milling to reduce web thicknesses. The attachment straps will be machined to size and stretch-formed to proper contour.

Holding fixtures have been designed, and the positioning of components has been determined. Existing welding equipment and associated fixtures used in previous contracts have been incorporated into the build plans for economy and to demonstrate the adaptability of the equipment on hand (Figures 3-10 through 3-14).

Coordination will be established with Quality Assurance to develop inspection techniques and requirements applicable to the main LH_2 tank in compliance with the provisions and requirements delineated in Appendix E of the Program Management Plan - Quality Assurance Program.

3.2.3 Cryogenic Insulation of LH_2 Tanks

The dual LH_2 conical fuel tanks will be individually cleaned, primed, and internally insulated with a foam system, which present a greater challenge than encountered on other programs. Foam insulation can be

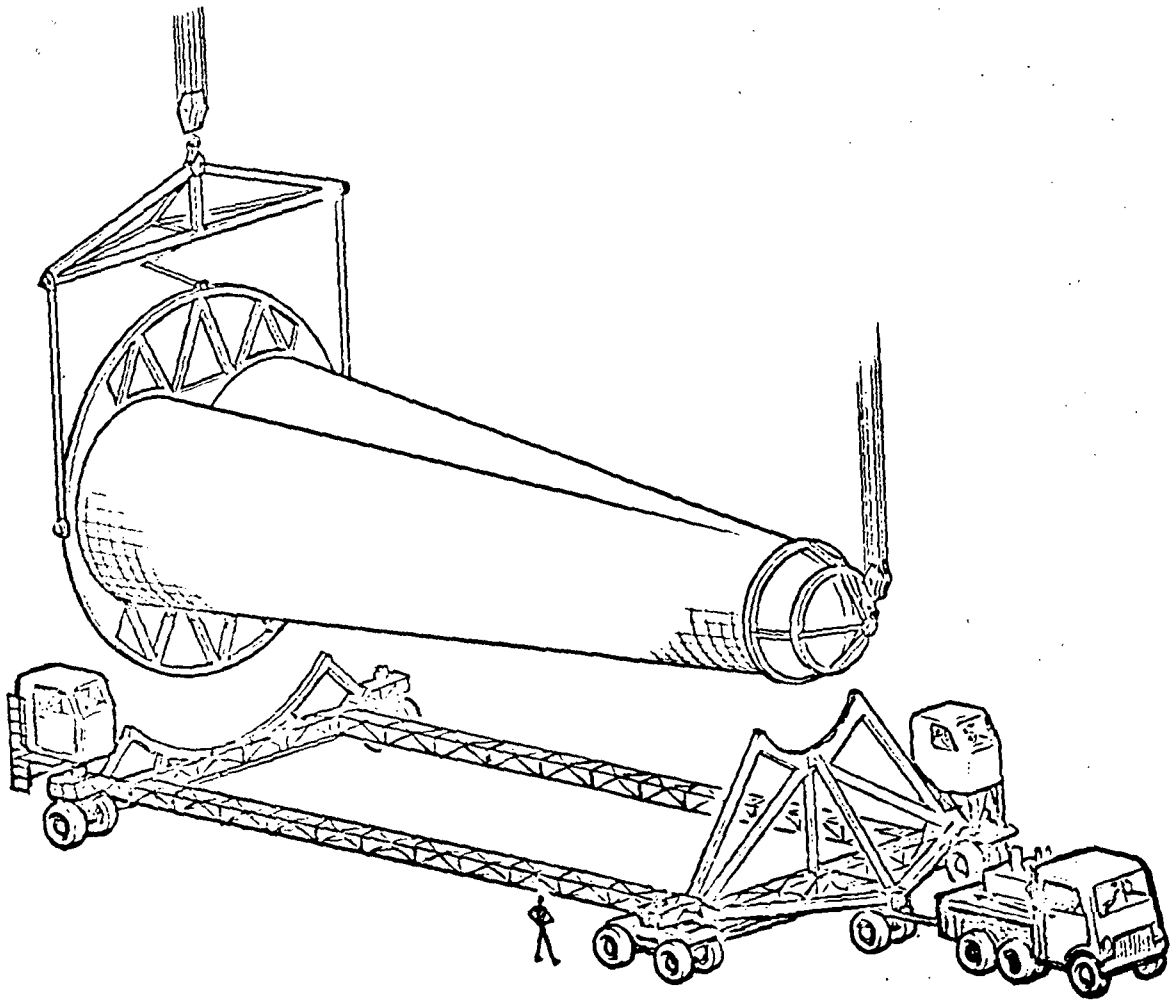


Figure 3-6. Tank Handling and Transport

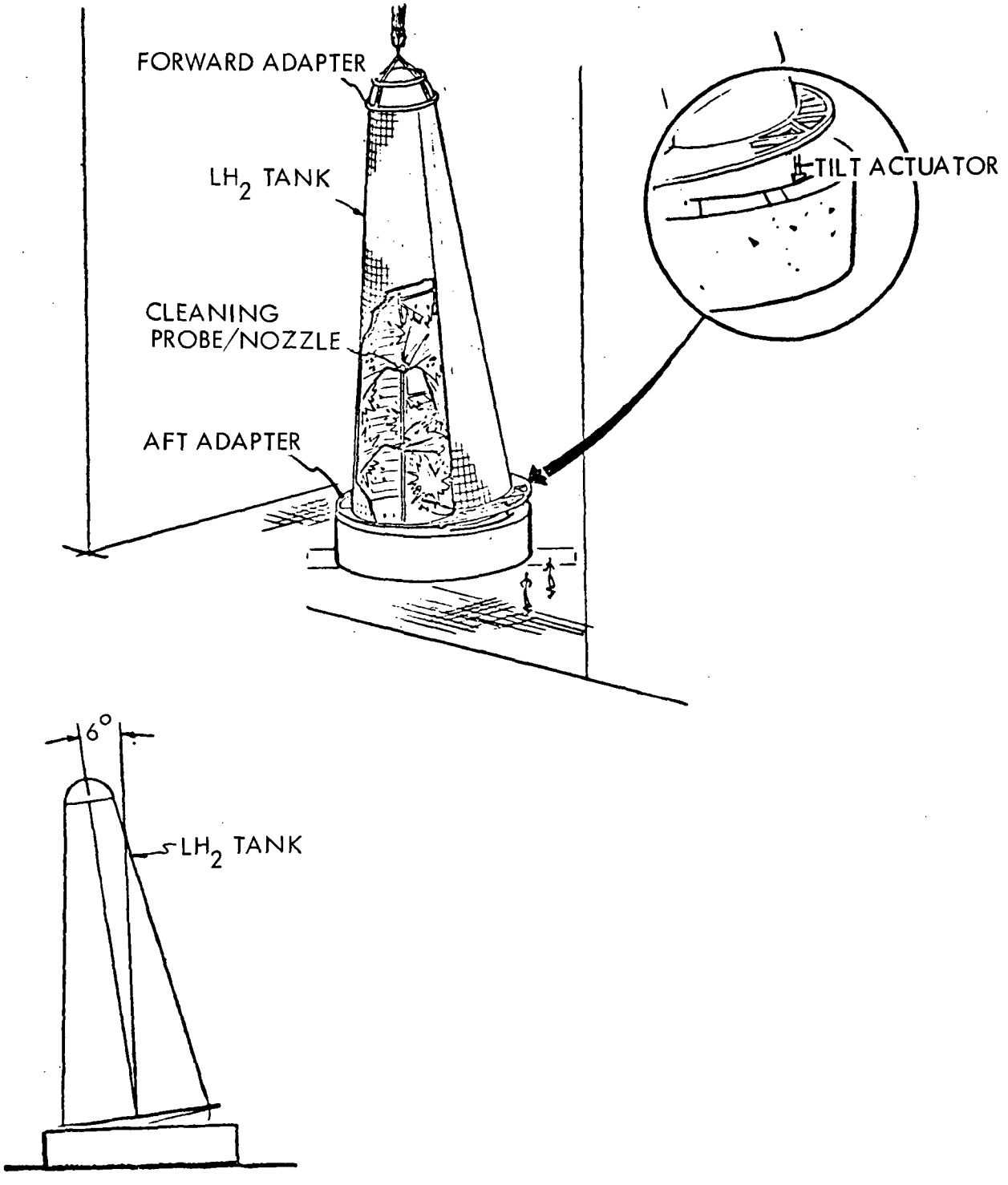


Figure 3-7. Main LH_2 Tank Cleaning

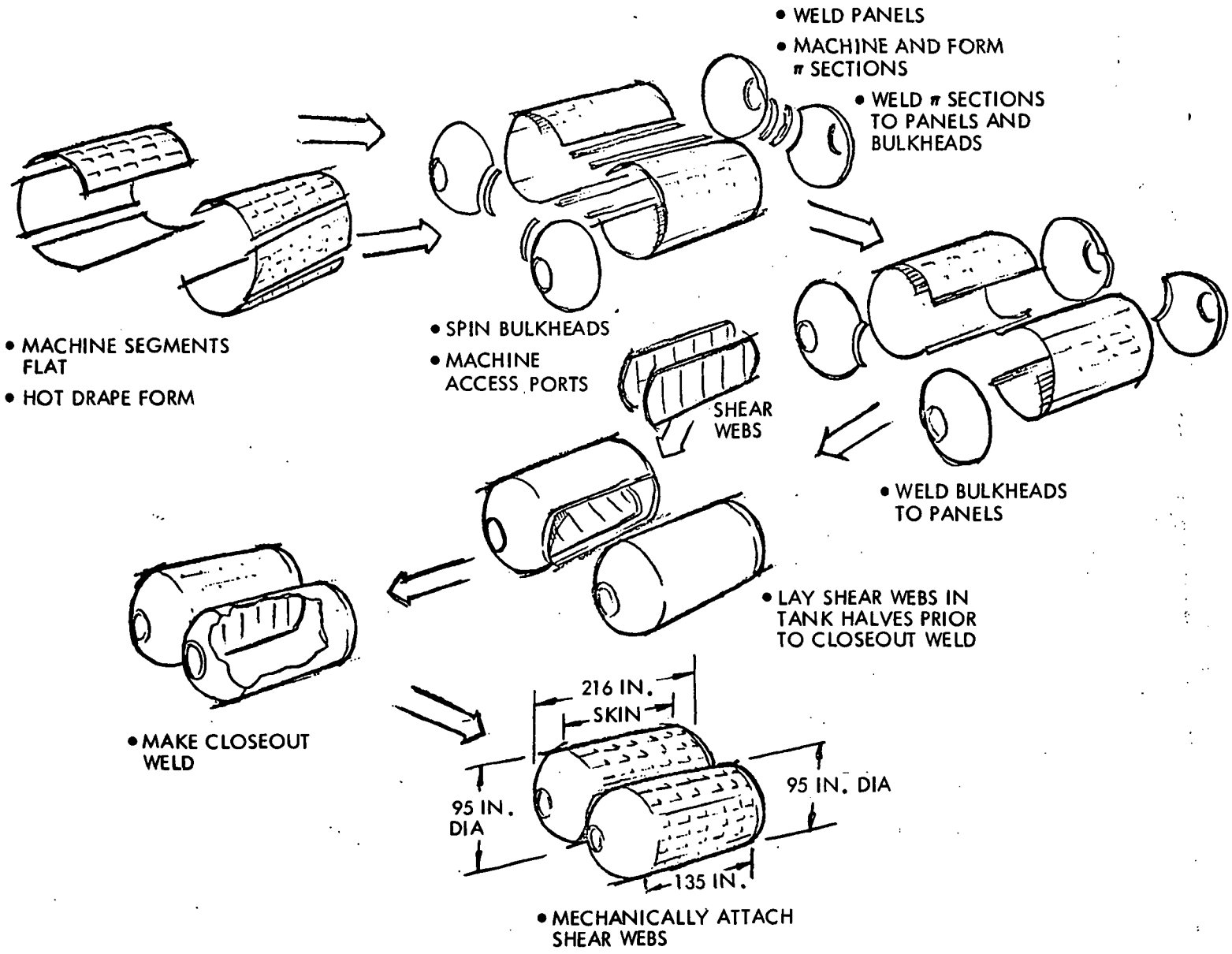


Figure 3-8. LH_2 Test Tank

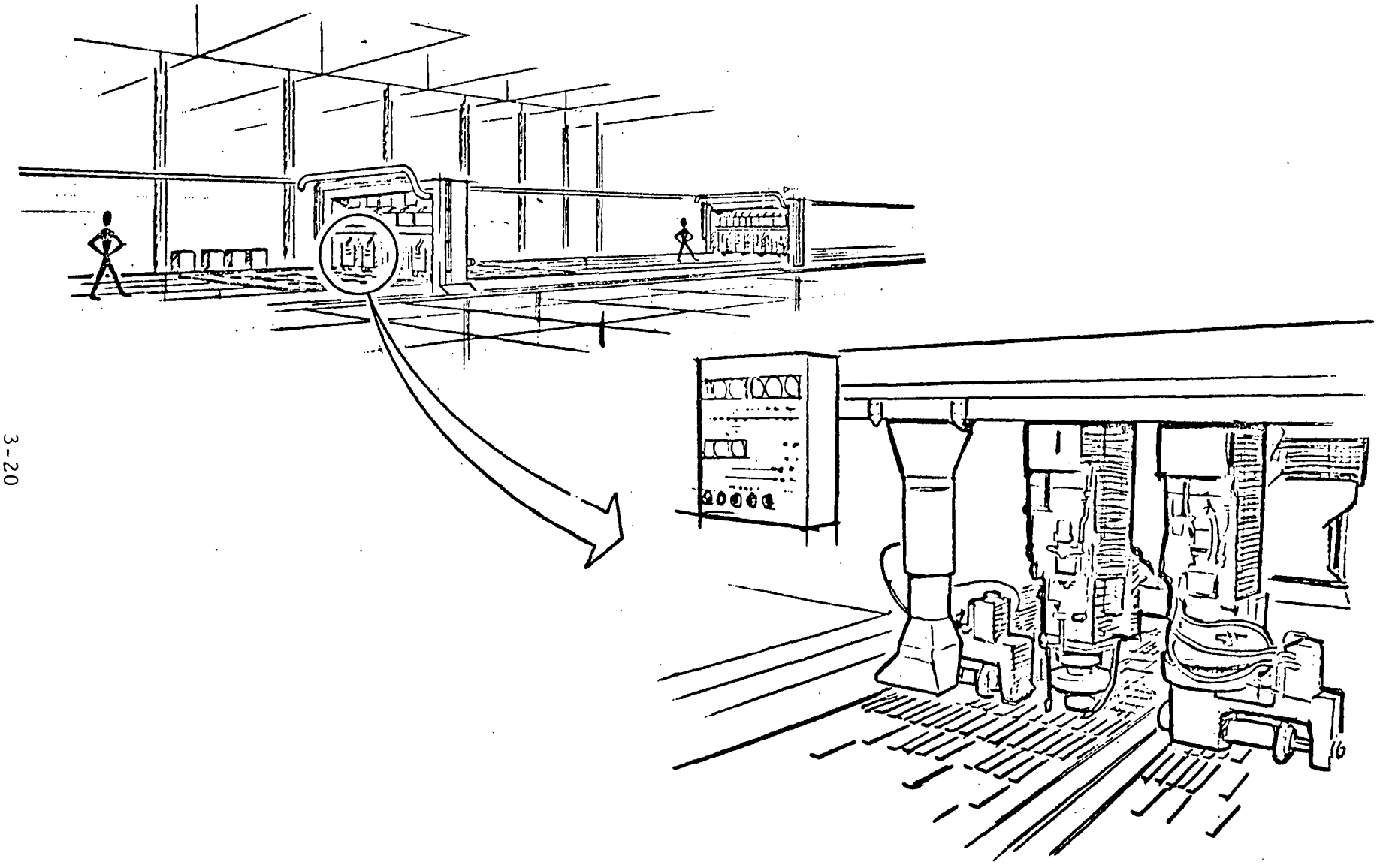


Figure 3-9. LH_2 Test Tank Panel Machining

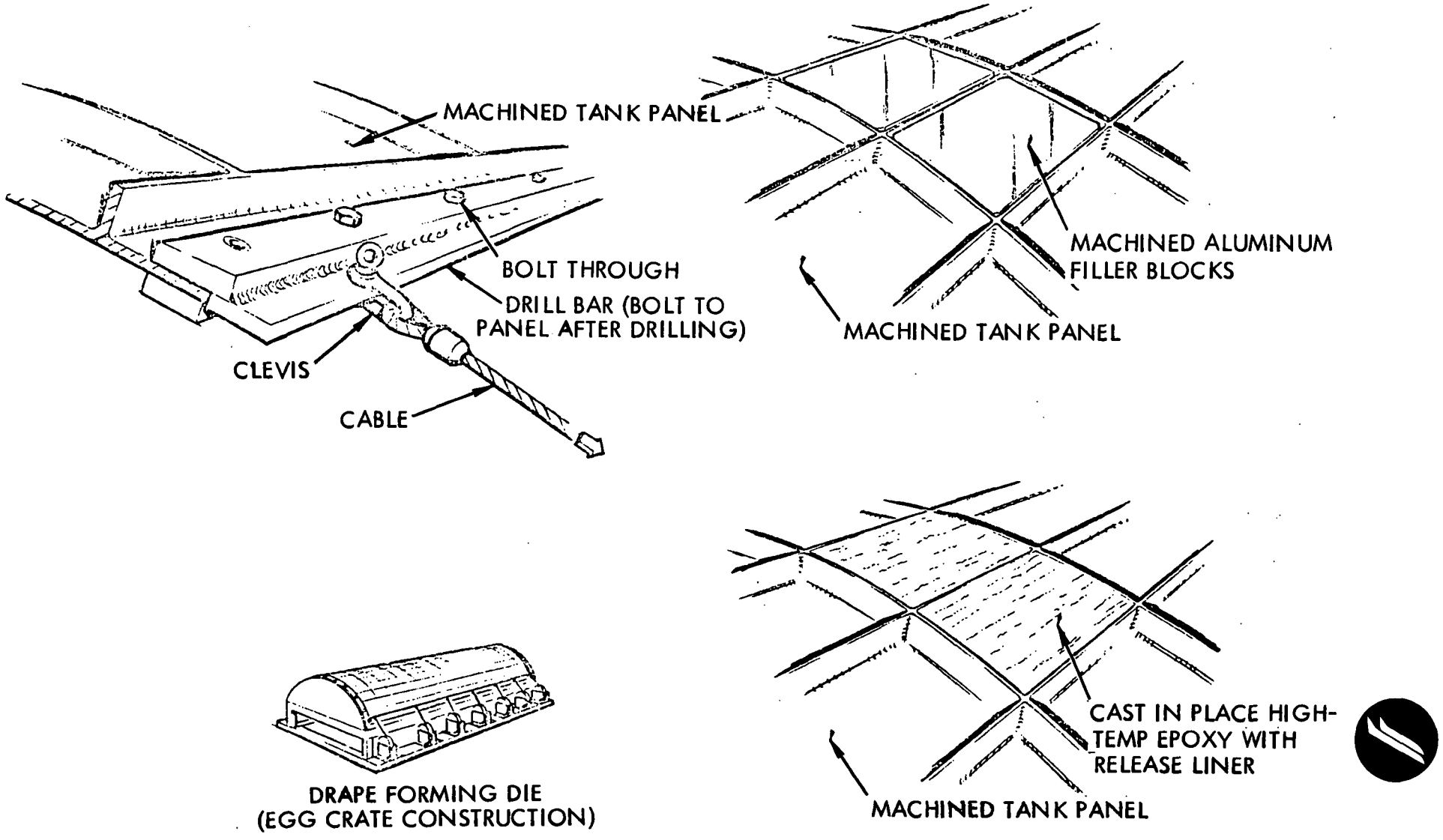


Figure 3-10. LH_2 Tank Panel Hot Drape Forming

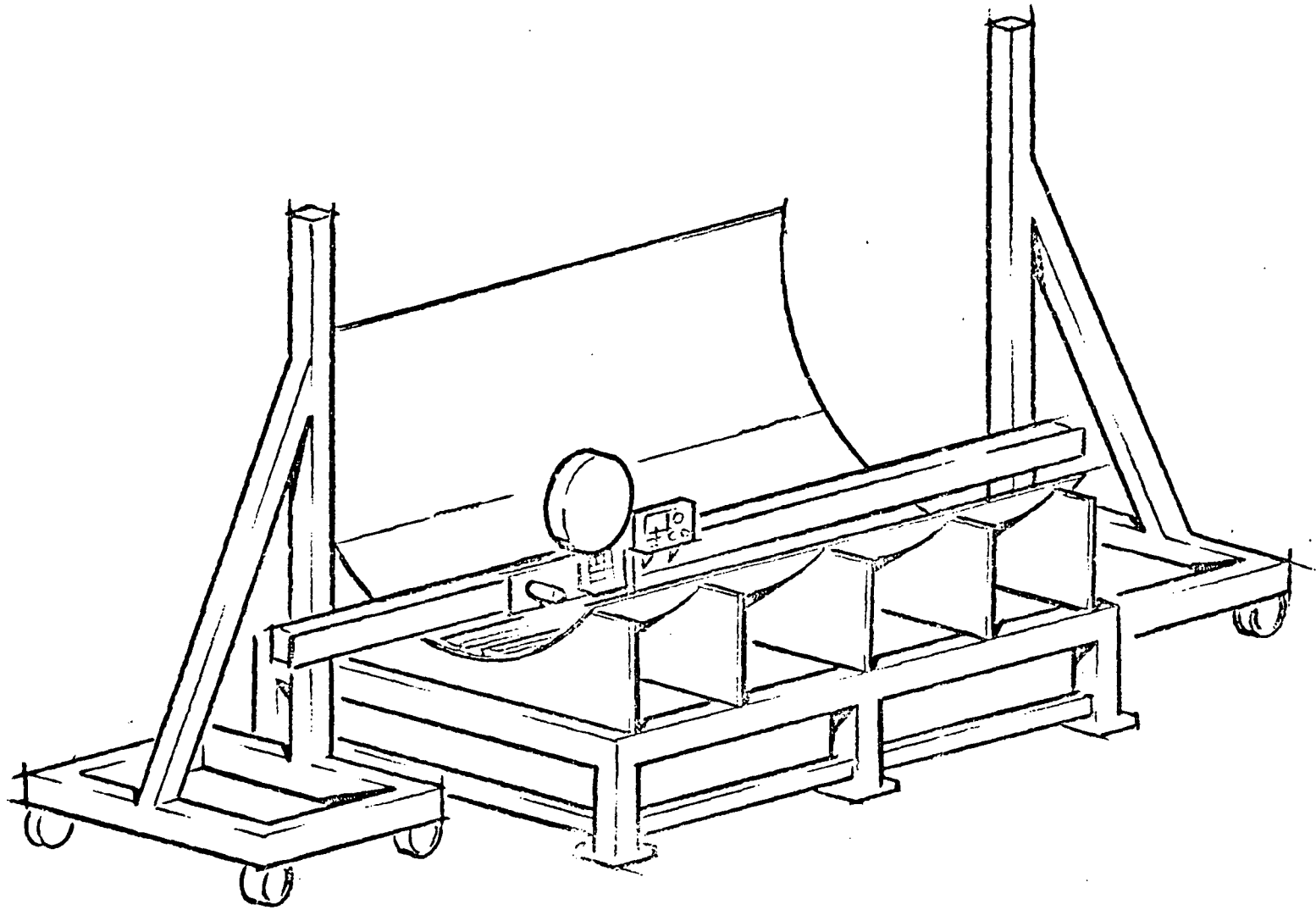


Figure 3-11. LH_2 Test Tank Panel Weld (Skate Machine)

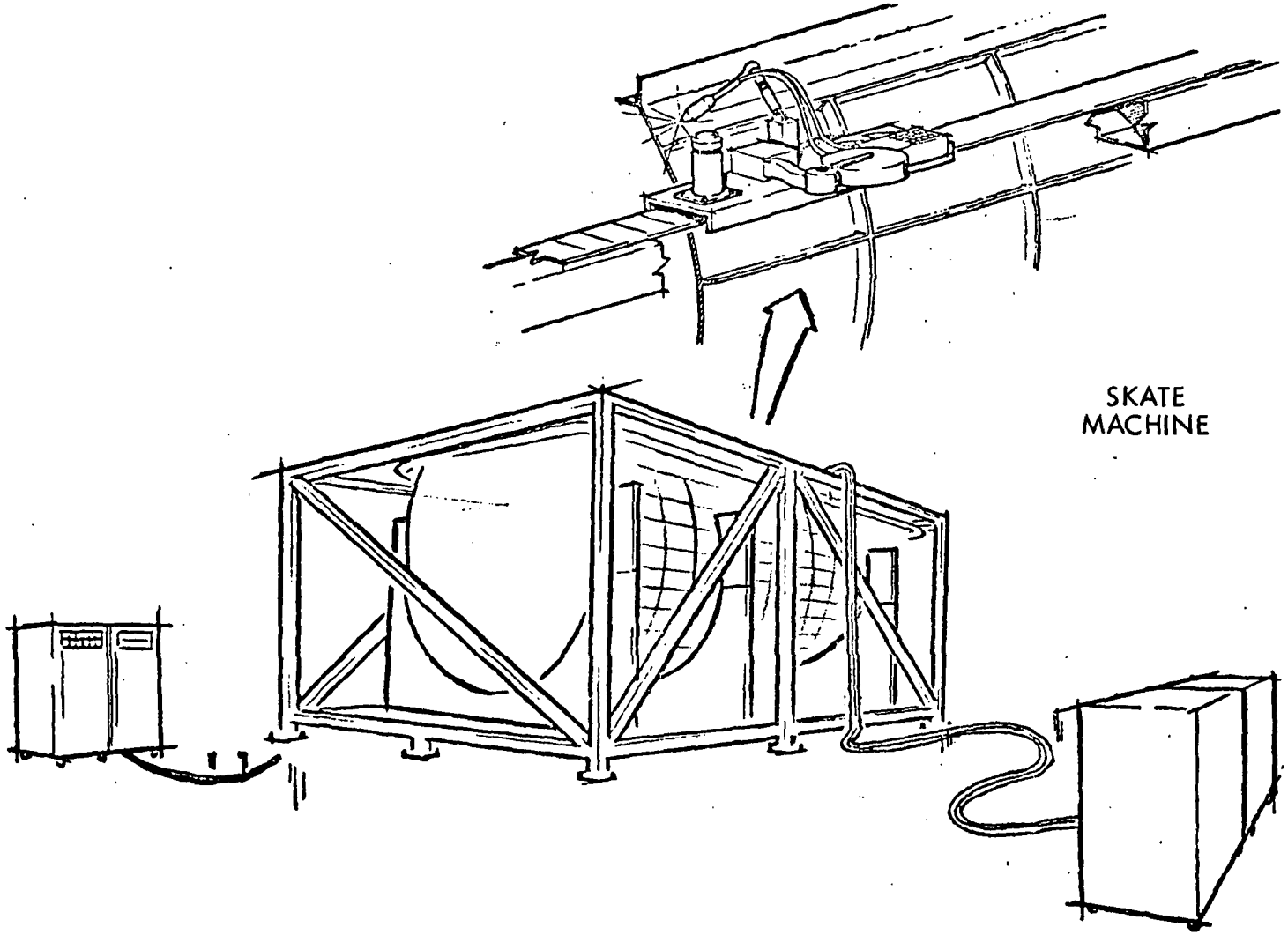


Figure 3-12. LH_2 Test Tank Extrusion to Tank Section Weld
(Final Assembly Weld Tool)

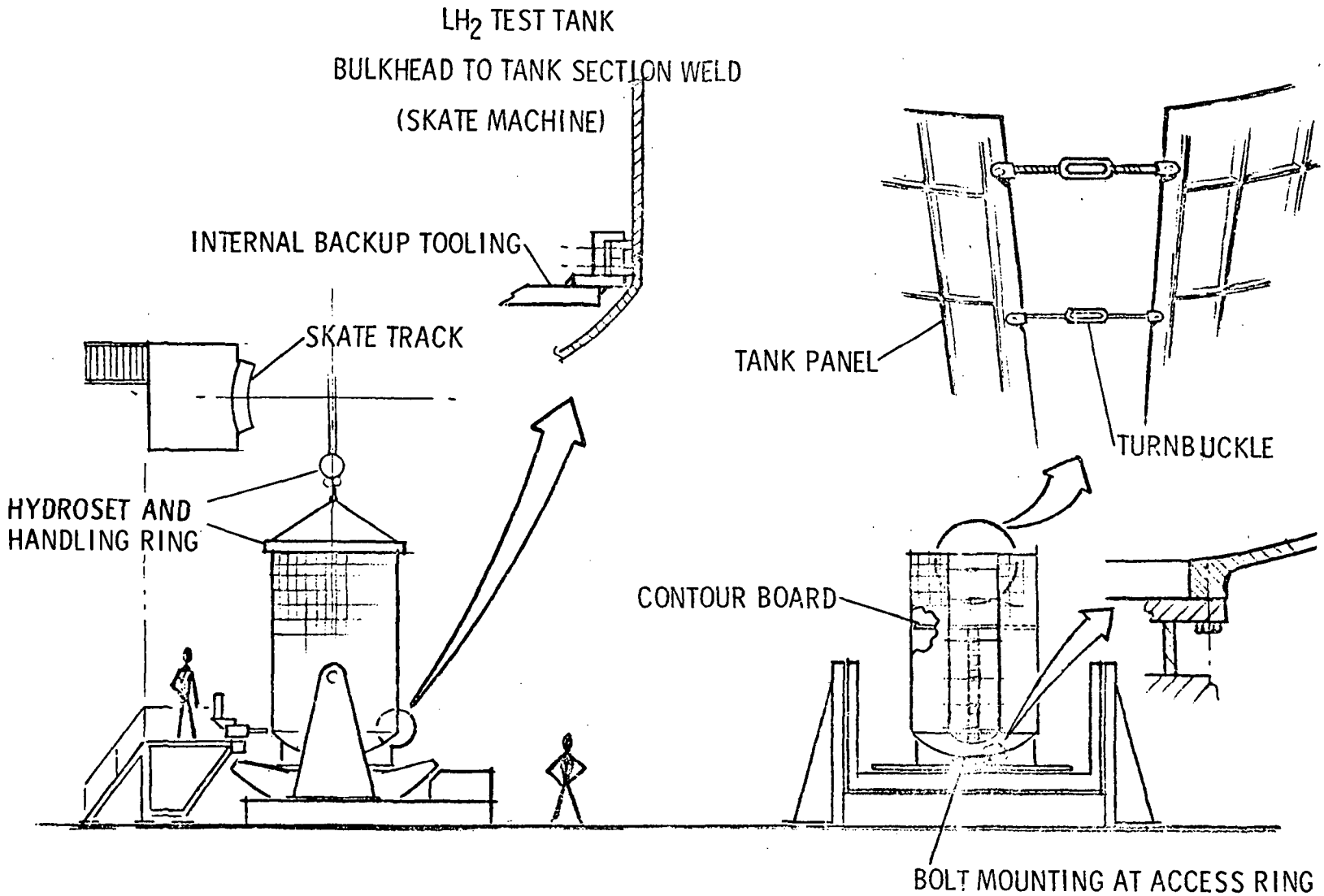


Figure 3-13. Existing 7100041 Weld Positioner (Sciaky)

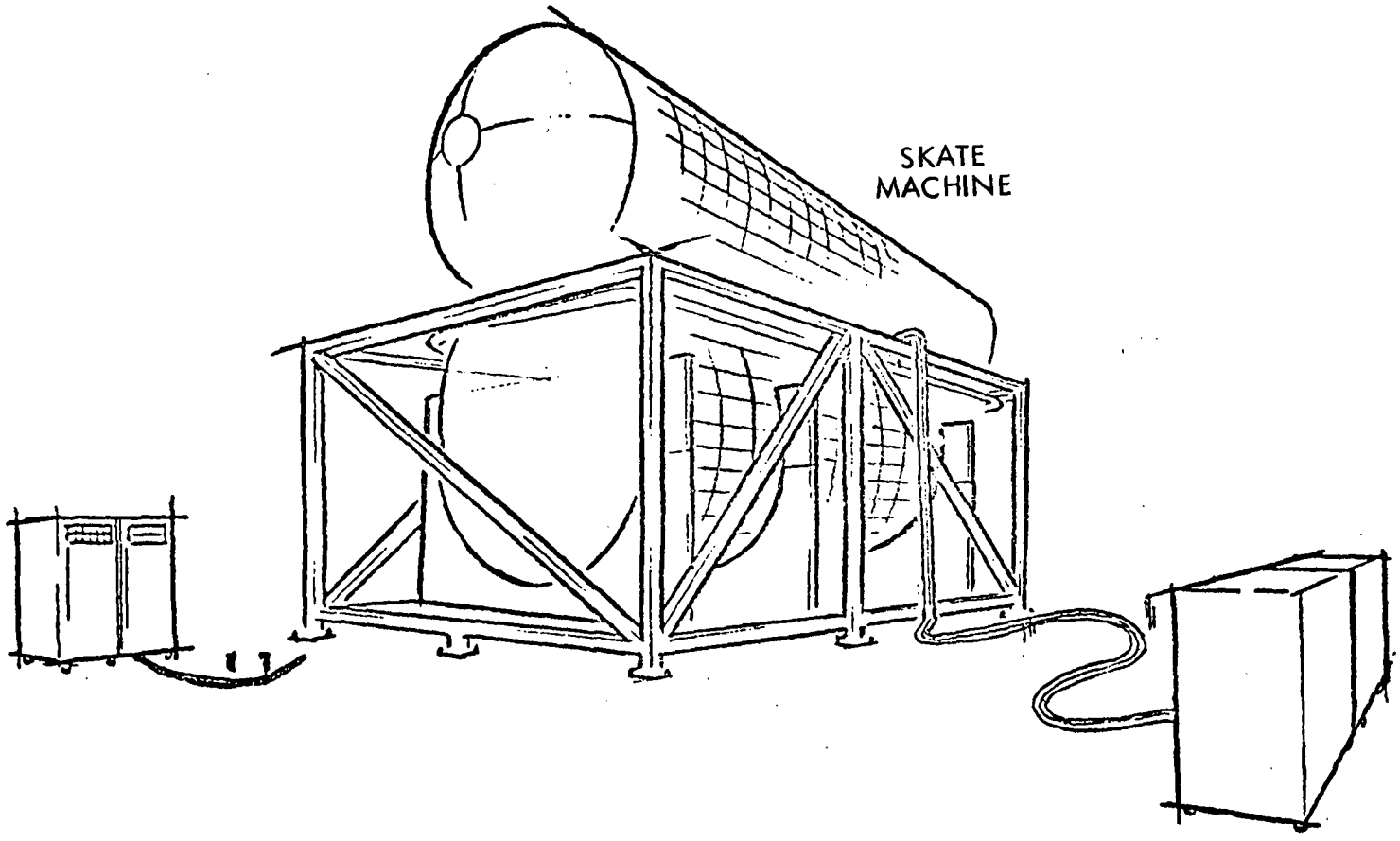


Figure 3-14. LH_2 Test Tank Closeout Weld (Final Assembly Weld Tool)

applied to the individual half-tank interior wall by spray application or by use of prefitted foam blocks. Personnel accessibility for installing work platforms and equipment required in assembly, processing, cleaning, and inspection is a manufacturing concern due to the tank size and the relatively small bulkhead openings. Exterior foam will also be applied, in the valleys where the connector beam has been welded, and in the areas of the bulkhead access ports.

The procedure considered most feasible will be to internally spray-foam each one-half tank individually before welding to the connector beam. Each one-half tank will have had pneumostat and penetrant inspection before insulation is applied. Each tank half will be cradled in a fixture (Figure 3-15), open face to one side. Foam spraying and machining to internal bulkheads and tank wall will be performed in this position.

After the tank components have been joined (in a horizontal position) the interior welded areas will be either spray-foamed and machined or closed out with precast foam blocks adhesively bonded. The insulation will be sealed with an organic coating prior to joining (welding) of the tank components. Closeout areas will be sealed after welding. All inspection sequences will be developed in compliance with the provisions and requirements delineated in Appendix E of the Program Management Plan - Quality Assurance Program.

After the tank components have been joined (in a horizontal position) the interior welded areas will be either spray-foamed and machined or closed out with precast foam blocks adhesively bonded. The insulation will be sealed with an organic coating prior to joining (welding) of the tank components. Closeout areas will be sealed after welding. Dye penetrant and X-ray inspections will be performed following completion of each weld operation and before application of foam insulation.

Current technology includes many techniques and processes applicable to cryogenic tank insulation. The S-II LH_2 tanks were spray-foam insulated on the exterior. Since the tanks were true cylinders, spray-foaming and machining presented no application problems. The half shell conical LH_2 tank configuration for the orbiter requires that machining of the concave and tapered surfaces be accomplished by making longitudinal passes with convex-faced phenolic cutters and programmed tool and machine controls.

3.2.4 Thermal Protection Systems

A lightweight reusable insulation system must be provided to protect the orbiter from reentry temperatures as high as 3000 F. The current engineering baseline vehicle utilizes a nonmetallic reusable insulative panel concept. The two materials selected for the Block I and Block II baseline concepts are carbon/carbon composites and reusable external insulation (REI), which are identified as major manufacturing problem areas (Figure 3-16).

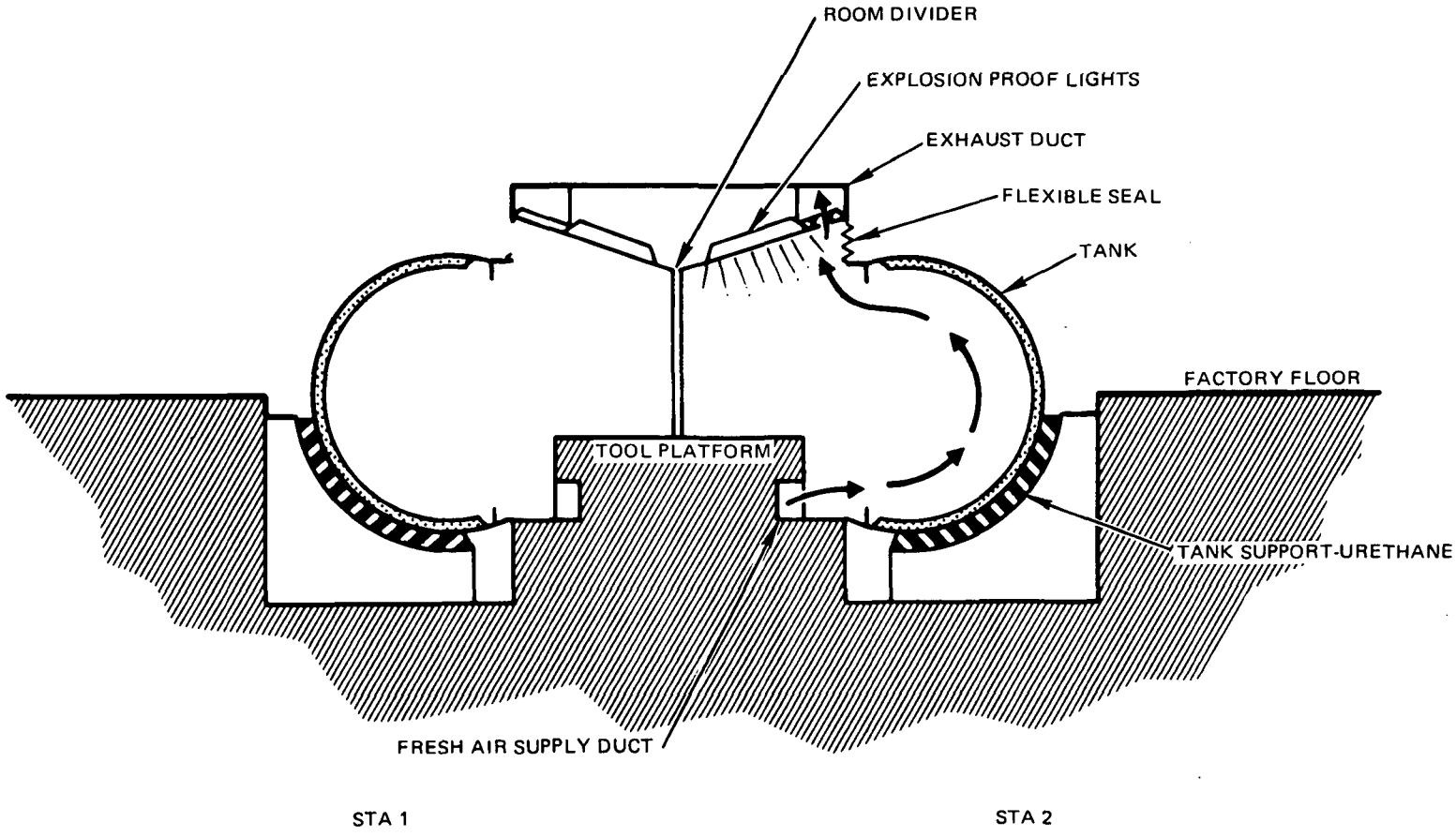


Figure 3-15. Main LH_2 Tank Insulation Attach Concepts, Limited Life and 100-Mission Life

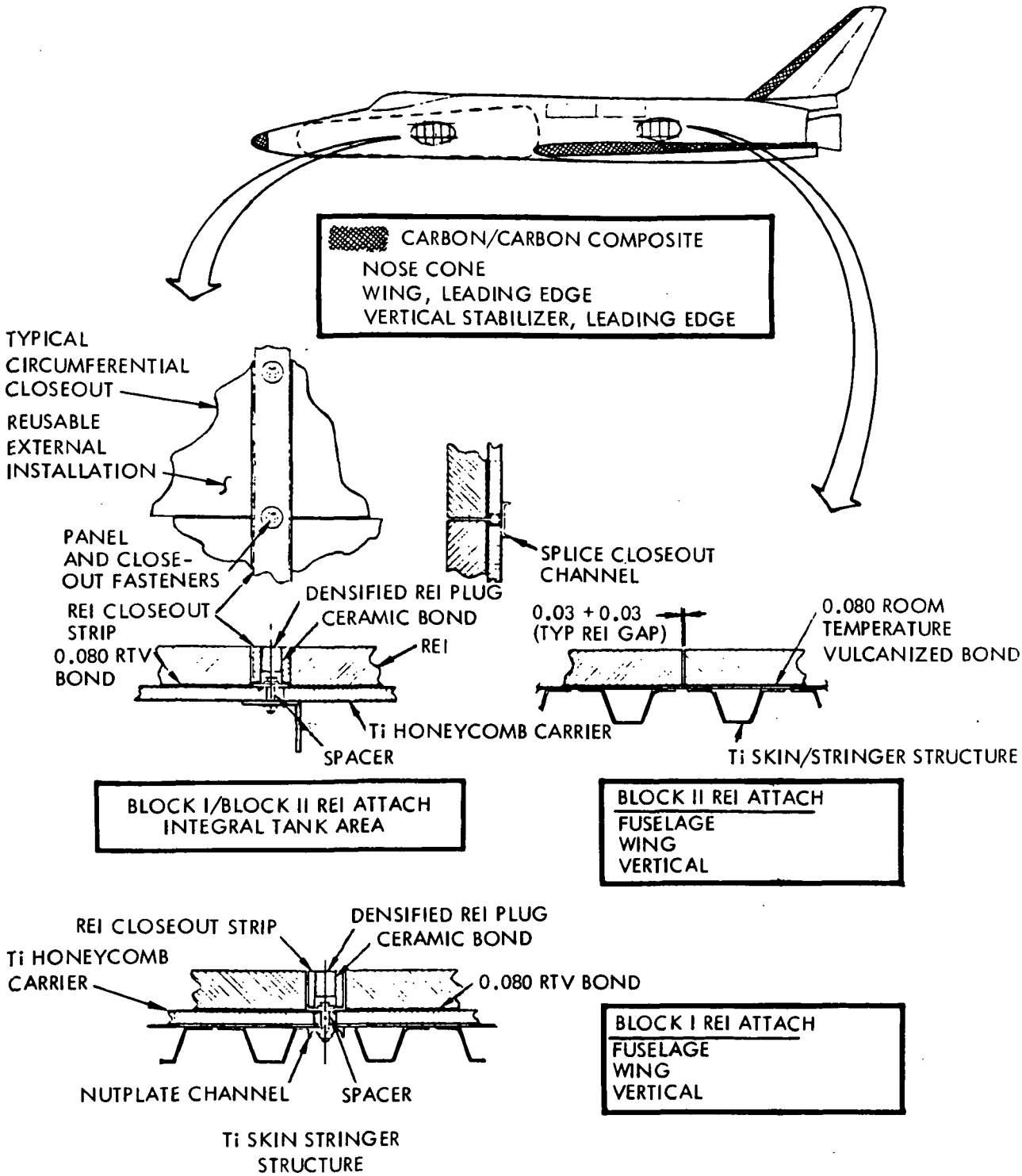


Figure 3-16. Reusable External Insulation Attach Concepts, Limited Life and 100-Mission Life

The primary concern is that the carbon/carbon composites and REI materials may not be available and that all of the related assembly and installation problems may not be resolved in time to support the present orbiter schedule.

Alternative thermal protection system heat-shield concepts that can be produced will be used if the need arises. These systems are primarily of the reusable metallic radiative-heat-shield type. If, however, it is decided that a reusable heat shield is not required on the first vehicle, the proven highly reliable ablative heat shields may be used. The following paragraphs describe the state of the art and technology advancements that have been made in the development of these alternative heat shields.

Reradiative Heat Shields

The high-temperature reentry surface requirements have directed material selection toward superalloys, such as Haynes 188, TD-Ni-Cr, and Inconel 625. Manufacturing has coordinated with Design Engineering in the development of practical designs that are within the manufacturing state-of-the-art. Fabrication of specimens has progressed to panels as large as 18 by 36 inches, representing full-size orbiter TPS panels. Significant results have been achieved in fabrication and processing techniques, such as machining, forming, and joining.

Machining. Thermal protection system panel fabrication required the development of manufacturing techniques for metal-working and machining processes. Material removal was accomplished with standard machining techniques. Haynes 188 alloy has work hardening characteristics and presented difficulties in material burr roll-up and excessive tool wear. These difficulties were reduced by refinement of cutter geometry, improved specimen backup, and holddown tooling techniques. Further development is required to reduce costs.

Chemical Milling. Several solutions were developed for etching the candidate high-temperature alloys and refractory metals. Processing requirements, such as temperature, solution agitation, and concentration, were investigated. Etch rates were determined for each alloy.

Laser Cutting. Laser beam equipment has been evaluated and methods have been established to cut some of the candidate materials. To date, cutting of titanium alloys and ceramics has been accomplished with a high degree of success, while cutting of other metals is still being developed. Titanium can be rough cut at rates up to 200 inches per minute at depths to 1-1/2 inch. It is feasible that cutting rates and finish can be improved through the use of different lenses and gas flows. The laser has the distinct advantage of having no moving parts, which eliminates tool wear. Continued development will expand the economical equipment applications.

Forming. Various forming tests were conducted to determine workability, minimum bend radii, and springback standards. The tests also provided information on tooling requirements imposed by design configuration. Forming processes, such as brake forming, hydropress, coin dimpling, and progressive corrugated die forming, were employed during test-panel fabrication. Conventional manufacturing methods and tooling appear practical for candidate materials. Thoria-dispersed nickel-chrome material does not have adequate elongation properties for severe forming. Orange peel, microsurface cracks, or rupture occur if the limitations are not considered. Material grain direction is also critical.

Welding. Fusion, electron beam, and resistance welding processes are being evaluated to determine the most feasible joining methods for heat-shield panels. Selected design concepts are being evaluated to determine the preferred welding method. Preferred methods are generally assessed by the resulting joint properties. For example, tests have shown that fusion welding degrades TD-Ni-Cr to a much greater extent than spot welding. Other candidate materials tested were successfully welded using the gas-tungsten arc process. Resistance spot welding was satisfactorily achieved on all the candidate materials.

Electron beam welding is being evaluated in the fabrication of stiffened panels. The results, to date, have been satisfactory on panels up to one square foot. Evaluation is continuing for fabrication of larger panels.

North American Rockwell has produced sine-wave-welded structural beams of titanium and CRES for company-produced aircraft and other aerospace firms. Further refinements of the process are continuing for 6Al 4V titanium, Rene 41, Haynes 188, and Inconel 718. Techniques for fabrication of wedge-shaped, curved, straight, and slant cap beams are being evaluated.

Vacuum Brazing. Haynes 188 and Inconel 625 test panels having corrugated cores and bead-stiffened face sheets have been successfully vacuum-furnace-brazed in sizes as large as 18 by 36 inches. Vacuum-brazing has been performed at a temperature of approximately 2160 F with a nickel-chromium-silicon brazing alloy.

Mechanical-property testing of the brazed and parent metal Haynes 188 has been conducted at room temperature and also at 1800 F.

Joining methods for the thoria-dispersed nickel-chrome (TD-Ni-Cr) alloy have been evaluated. Vacuum-furnace brazing appears to be one of the most promising joining processes. Brazing tests using a selected braze alloy were successfully performed at 2375 F. Subsequent testing of this and

other selected braze alloys will provide the technology for successful furnace brazing. Two critical phases of the TD-Ni-Cr braze cycle are the vacuum-pressure levels and the heating cycle. The material is sensitive to low vapor pressures at specific temperatures and dwell times. Discoloration and possibly some embrittlement may be expected if the critical factors are disregarded.

A 3000 F production-size vacuum furnace was installed recently at the Space Division to provide facilities for brazing superalloys and other high-temperature materials.

Mechanical Fasteners. The use of mechanical fasteners will be necessary for assembly in various areas of the orbiter, such as attachment of thermal protection system structure and supports. High-temperature environments will require that some fasteners be made from high-temperature-resistant materials, such as Haynes 188, TD-Ni-Cr, and Inconel 601, which are candidate materials for high-strength, high-temperature fastener materials. North American Rockwell has extensive experience in the selection, design application, and installation of mechanical fasteners for many aerospace applications; however, further refinements will be required in special applications where possible degradation of fasteners is caused by torque pressures, seizure, reuse, and hold tolerances. Testing of mechanically fastened specimens will be accomplished to obtain room and elevated temperature design data and manufacturing producibility information.

Ablative Heat Shields

Consideration is being given to the use of ablative heat shields as the backup system for the first shuttle vehicle. These systems have been demonstrated successfully in the Mercury, Gemini, and Apollo Programs.

A development program, recently completed under NASA Contract NAS 1-9943, successfully demonstrated the ability to fabricate lightweight ablative panels at a significantly lower cost than those used on the Apollo command module.

A new program is in progress to evaluate low-cost ablative heat shields as potential alternatives to the REI and carbon/carbon composite systems. The project includes refinements in formulation, fabrication, processes, assembly, and testing of ablative heat shield panels. In addition, heat-shield studies have been conducted which have resulted in establishing producibility factors, fabrication limitations, and cost estimating data.

Ablative prototype panels for thermal and structural testing and fabrication methods have been completed. Company sponsored programs and the NASA Contract (NAS 1-9943) have been completed on reentry type ablator insulation systems utilizing fiberglass honeycomb matrices.

Candidate ablative heat shield materials being evaluated for the Shuttle Program are:

1. AVCOAT 5026 (Apollo)
2. DC-325 (Gemini)
3. Phenolic microballoon elastomer
4. Nylon-Phenolic
5. Spray or brush-on coatings
6. Cork

The primary candidate material will be the AVCOAT 5026 ablative system because of the extensive information obtained in the Apollo Program.

Items 1 through 4 require a honeycomb matrix because of their low cohesive strength during thermal cycling. It is considered that two or three of the above could be used in combination to obtain greater economies. For example, the AVCOAT 5026 material can be used in the high-heat-flux area. The AVCOAT material has a lower ablation rate in comparison to cork but is considerably higher in cost than cork.

Contact has been maintained with Quality Assurance to establish reliable, low-cost nondestructive inspection methods for ablative panels. The liquid-crystal thermographic technique shows considerable promise in detecting core-fill-to-face-sheet voids. Liquid-crystal sheets are vacuum-bagged to the panel facing and radiant-heated. Visual observation reveals color changes which detect the presence of surface defects. The technique offers the advantages of low-cost rapid inspection, ease of interpretation, and vivid display of the cell-fill condition.

All inspections applicable to this section will be developed in compliance with the provisions and requirements delineated in Appendix E of the Program Management Plan - Quality Assurance Program.

3.2.5 Crew Module Assembly

Detailed study of the crew module design, materials, assembly sequences, and functional requirements has exposed three areas of concern. They are the internal frame attachment, windshield assembly, and hatch seals.

Internal Frame Attachment

A mechanical fastener approach to attaching structure to the inside surface of the crew module has been selected over bonded-on attach fittings, thus avoiding the complexities of bonding and its associated processes.

A concern is presented in the precise location of holes for attachment of bracketry to support the crew module, equipment bay, and subsystems on the internal surface of the shell structure. Location of the exact hole pattern on the large smooth interior surface of the shell would be extremely difficult.

To perform this assembly without extensive use of collapsible locating, drilling, and reaming tooling, studies were conducted using experience gained on the Saturn II forward skirt attachment to the LH_2 bulkhead. Results of these studies and coordination with Design Engineering developed the present approach to this condition, which consists of using the numerically controlled sculpturing tape and adding pilot hole locations following grid machining. The structure plate will be turned over on the machine during the machining operation and reindexed for the pilot-hole operation, establishing a grid indexing reference system on the internal surface of the crew module shell (Figure 3-17).

Windshield Configuration

The windshield installation, integrated with the total system, of aluminum structure, glass, insulators, and seals presents a concern during assembly.

Manufacturing Engineering producibility reviews with Design Engineering resulted in a machined windshield frame welded to the cabin shell. The technology evaluated was based on previous windshield experience and known welding processes. The effects of postwelding in proximity to close-tolerance machined surfaces is avoided in the windshield design and assembly sequence.

The glass installation and materials used, which are similar to those used on the Apollo system, consist of fused silica outer glass surrounded by and suspended in Inconel mesh sealant. The inner glass, which consists of two panes of aluminasilicate, is surrounded by a molded room-temperature-vulcanizing (RTV) seal. Isolation between the inner and outer glass is maintained by marinite insulators and dynaflex insulation augmented by a purge system and reusable external insulation (REI) framing all glass areas along the vehicle moldline surface. Special emphasis on tooling, parts protection, and handling is planned to preclude damage to the glass panels during, and subsequent to, the installations (Figure 3-18).

Ingress and Egress Hatches

The ingress and egress hatches, with dual pressure and temperature requirements, present a complex sealing problem during fabrication and assembly.

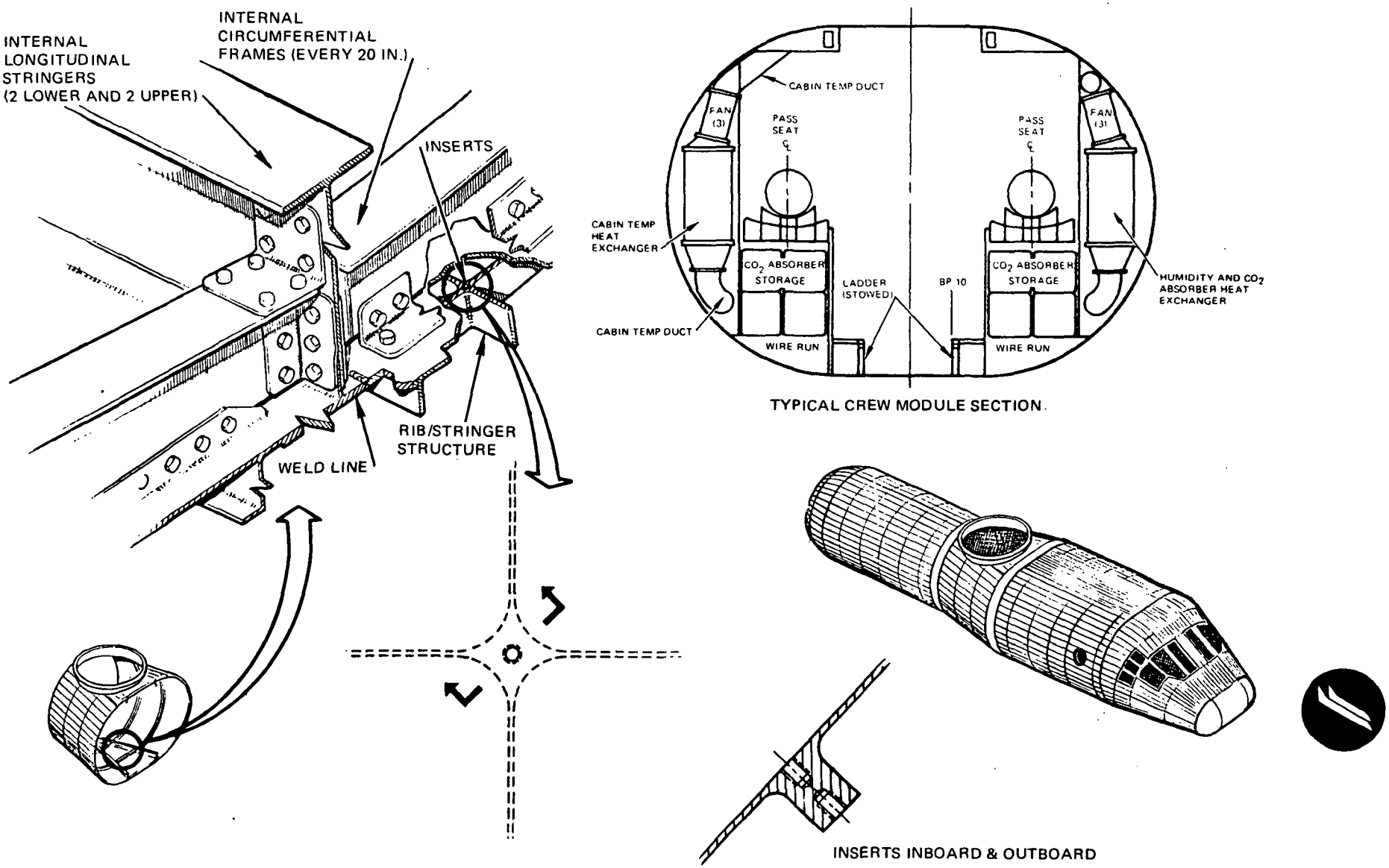


Figure 3-17. Crew Module Frame Attach

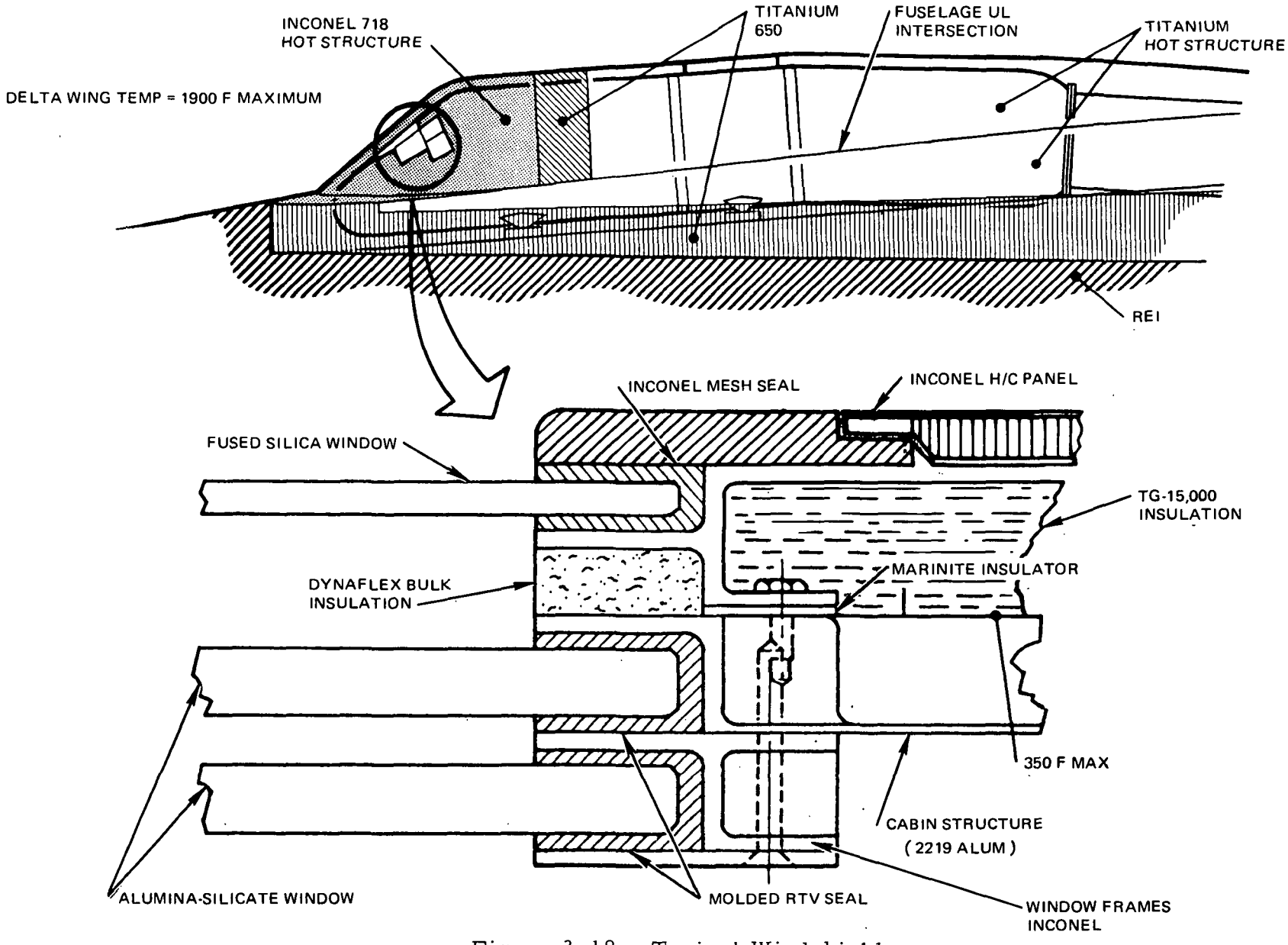


Figure 3-18. Typical Windshield

One system of high-temperature sealing that warrants analysis is that used on the X-15. The advancement of other sealing technology for application to the shuttle program is currently under way.

All inspections applicable to this section will be developed in compliance with the provisions and requirements delineated in Appendix E of the Program Management Plan - Quality Assurance Program.

3.2.6 Wing Attach

The wing to fuselage mate is primarily a state-of-the-art operation but is a concern due to the large component sizes and the critical alignment required to insure proper installation within design tolerances.

The present wing to fuselage attach joint utilizes large titanium 6Al 4V forged fittings which are located in two places on each of the four wing spars. One fitting is located outboard where the body frame intersects the wing box; the other interfaces with the fuselage truss assembly at the extreme inboard end of the wing. Each joint requires the installation of four titanium bolts to secure the mating fittings together (Figure 3-19).

During mating operations the wing will be mounted on a combination transportation and mating fixture. This fixture will incorporate provisions for microadjustment of the wing assembly to bring the attach interfaces into proper alignment for drilling, reaming, and fastener installation. Gross movement of the fixture will be provided by air-operated glide pads mounted on the base of the fixture. To insure proper rigging of the assemblies, a reference system utilizing conventional optics as well as laser alignment systems will be provided. Master tooling will be used to fabricate the assembly jigs and mating fixtures to insure proper alignment at final assembly.

All inspections applicable to this section will be developed in compliance with the provisions and requirements delineated in Appendix E of the Program Management Plan - Quality Assurance Program.

3.3 ITEMS CAUSING SUBSTANTIAL PROGRAM IMPACT

Items that could cause substantial program impact were assessed by manufacturing task teams assigned to conduct indepth evaluations of manufacturing and engineering design issues. Trade studies and design analysis were performed by Manufacturing in conjunction with Design Engineering during the Phase B study to assure manufacturability of the orbiter. These studies included factors concerning technology, tooling, material, handling, fabrication, assembly, installations support equipment, manufacturing check-

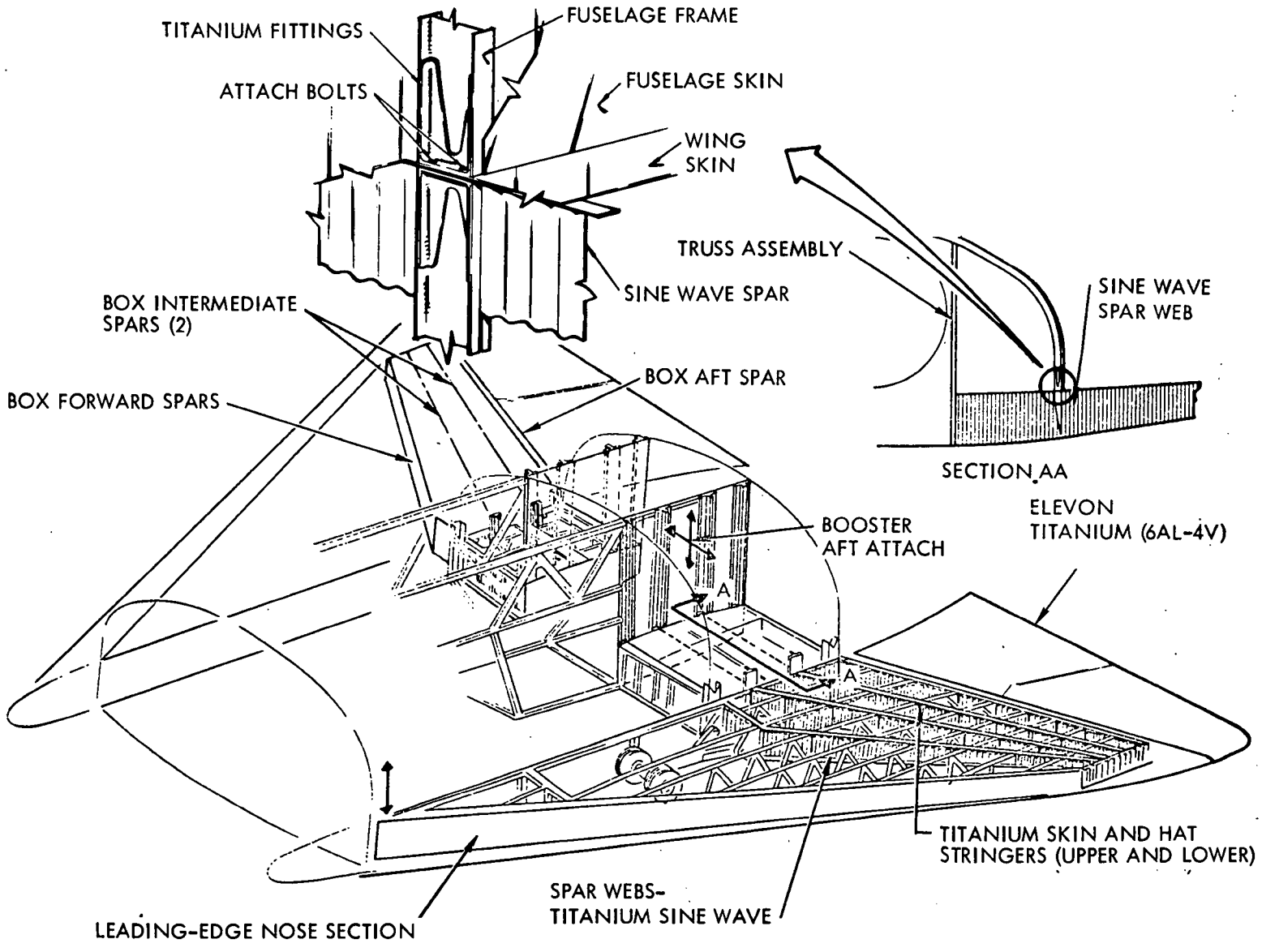


Figure 3-19. Wing Attach

out, personnel, cost, schedule, facilities, quality assurance, safety, and transportability. The conclusions reached by these teams were presented to the Production Operations Review Board to establish the optimum manufacturing methods and processes, based on current design vehicle configuration.

Results of these assessments and studies indicate that there are no areas in the present manufacturing plan that would present a substantial program impact. As discussed earlier, however, major problem areas have been identified (Sections 3.1.1 and 3.1.2) which do have the potential of becoming program impact items. One item of concern to manufacturing in this category is the nonmetallic reusable external insulation (REI). The development and availability of this material is critical to the present program schedule. Should a delay in development or production of this material occur, alternative methods will be used to ensure that program schedules are met. Development and manufacturing technology effort is in progress to employ ablators or a metallic thermal protection system constructed of superalloys (Section 3.2.4).

4.0 GOVERNMENT-FURNISHED EQUIPMENT, MACHINE TOOLS, AND EQUIPMENT

4.0 GOVERNMENT FURNISHED EQUIPMENT, MACHINE TOOLS, AND EQUIPMENT

This section contains an initial listing of the required government-furnished equipment and machine tools. Included in the listing which will be continually updated as an on-going task through Phase C, are:

1. Government-owned machine tools at the NR Space Division and Los Angeles Division with individual acquisition values in excess of $20,000 and having potential use for fabrication of details (Tables 4-1 and 4-2).

2. NR-owned machine tools at the Los Angeles, Tulsa, and Columbus Divisions, which supplement the government machine tools and which also can be utilized for fabrication of details (Tables 4-3, 4-4 and 4-5). These lists also cover only that equipment with an acquisition value in excess of $20,000.

3. Equipment required at the operations site, KSC (Table 4-6).

4. Equipment required at KSC for cluster firing (Table 4-7).

5. Equipment required at Edwards AFB for ABES and human factors tests (Table 4-8).

6. Equipment required at MSC for thermal control systems testing (Table 4-9).

7. Equipment required at Downey for laboratory testing (Table 4-10).

Table 4-1. Government Equipment to be Used at the Space Division

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
U0276260	Boring machine, horizontal	1954	45,540
P0327447	Boring machine, vertical	1952	60,760
U0341233	Boring machine, vertical	1953	72,468
U0409820	Boring machine, vertical	1953	57,843
F0310778	Boring machine, vertical	1952	233,326
U0276222	Boring machine, jig	1954	38,536
U0332429	Boring machine, jig	1952	21,130
U0274032	Boring machine, jig	1954	53,783
U0292781	Boring machine, jig	1951	37,138
U0339596	Drill machine	1962	64,485
U0339518	Drill machine, upright	1961	36,645
U0274636	Drill machine, radial	1954	23,293
U0504718	Drill machine, radial (Giddings, Lewis)	1957	33,730
U0359357	Grind machine, surface	1956	32,350
U0244518	Lathe, heavy duty engine	1952	31,066
U0275312	Milling machine, knee	1954	22,340
U0274041	Milling machine, knee	1955	22,340
U0385282	Milling machine, knee	1954	25,567
U0343419	Milling machine, knee	1952	20,745
U0282010	Milling machine, knee	1953	20,745
U0274034	Milling machine, knee	1954	27,740
U0339542	Milling machine, knee	1952	28,350
U0339591	Milling machine, knee	1953	28,101
U0440225	Milling machine, knee	1953	21,270
U0271735	Milling machine, knee	1954	22,092
U0476022	Milling machine, knee	1952	27,580
U0413256	Milling machine, bed	1963	162,608
U0126727	Milling machine, profiling	1951	44,805
U0395497	Milling machine, profiling	1951	48,428
U0274063	Milling machine, profiling	1954	62,862
U0505269	Milling machine, traveling housing	1960	145,665

Table 4-2. Government Equipment to be Used at the Los Angeles Division

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
U0413537	Machine center (Sunstrand)	1965	286,408
U0338697	Machining center (Kearney/ Trecker)	1960	137,790
U0338699	Milling machine, traveling housing (Kearney/Trecker)	1960	137,790
U0338700	Milling machine, traveling housing (Kearney/Trecker)	1960	137,790
U0229467	Profiler numerically controlled (Kearney/Trecker)	1963	342,122
U0300240	Boring machine, horizontal (Giddings/Lewis)	1954	43,925
U0504065	Boring machine, horizontal (New Britain)	1956	51,489
U0426477	Boring machine, horizontal (New Britain)	1952	66,020
U0130017	Boring/turning vertical (Bullard)	1956	53,549
U0451073	Boring/turning machine vertical (Bullard)	1951	60,384
U0130172	Boring machine vertical (American Steel Foundary)	1956	60,115
U0503420	Boring machine, jig (Kearney/ Trecker)	1955	23,792
U0339466	Boring machine, jig (Devlieg)	1960	74,100
U0273729	Boring machine, jig (Devlieg)	1953	36,600
U0427309	Boring machine, jig vertical (Pratt)	1953	37,266
U0338698	Boring machine, jig (Pratt)	1959	72,947
U0274310	Boring machine, jig (Pratt)	1954	20,540
U0568758	Boring machine, jig (Pratt)	1954	23,600
U0275138	Boring machine, jig (Hauser)	1954	23,881
U0274637	Boring machine, jig (Pratt)	1955	23,375
U0463802	Boring machine, jig (Pratt)	1952	33,429
U0463786	Boring machine, jig (Pratt)	1953	29,002
U0572604	Boring machine, jig (Pratt)	1954	36,556
U0298553	Boring machine, jig (Societe Genevoise)	1952	106,880

Table 4-2. Government Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
U0277601	Boring machine jig (Pratt)	1955	82,336
U0505123	Boring machine jig (Pratt)	1957	89,146
U0413535	Boring machine jig (Pratt)	1965	129,725
U0274328	Drill machine, radial (Oberlikon)	1953	45,250
U0569098	Drill machine, radial (Cincinnati Mill/Grind)	1955	24,420
U0274566	Drill machine, radial (Giddings/Lewis)	1953	32,474
U0504100	Drill machine, upright (Burg Tool)	1956	25,900
U0274784	Gear grinding machine	1953	44,502
U0339458	Grinding machine, ext cy (Brown/Sharpe)	1961	29,980
U0274972	Grinding machine, plg cu (Sheffield Corp)	1955	39,829
U0421101	Grinding machine, int cy (Bryant)	1952	22,042
U0274271	Grinding machine, int cy (Bryant)	1953	29,451
U0389787	Grinding machine, int cy (Heald)	1957	54,040
U0273383	Grinding machine, thread (Jones/Lamson)	1952	27,925
U0273750	Grinding machine, thread (Jones/Lamson)	1953	27,925
U0274491	Grinding machine, thread (Ex-Cell-O Corp)	1953	39,523
U0338616	Grinding machine, profiling (Sheffield Corp)	1959	35,200
U0303771	Grinding machine, jig (Pratt)	1957	61,550
U0338732	Grinding machine, jig (Pratt)	1960	84,451
U0330320	Lathe, heavy duty engine (American Tool Works)	1952	21,363
U0339479	Lathe, heavy duty engine (Leblond, RK)	1962	90,873
U0274948	Lathe, turret (Jones/Lamson)	1954	21,089
U0568765	Lathe, turret (Jones/Lamson)	1955	21,584

Table 4-2. Government Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
U0493766	Lathe, turret (Warner Swasey)	1953	24,445
U0446218	Lathe, turret (Warner Swasey)	1954	33,627
U0454897	Lathe, turret (Warner Swasey)	1955	28,278
U0358041	Lathe, turret (Jones/Lamson)	1953	34,040
U0358246	Lathe, turret (Jones/Lamson)	1953	34,040
U0207042	Lathe, turret (Jones/Lamson)	1952	34,058
U0392714	Lathe (Warner Swasey)	1952	20,525
U0274728	Milling machine, knee (Kearney, Trecker)	1954	21,880
U0274729	Milling machine, knee (Kearney, Trecker)	1954	21,880
U0274879	Milling machine, knee (Cincinnati Mill/Grind)	1953	22,090
U0275314	Milling machine, knee (Cincinnati Mill/Grind)	1954	22,340
U0382062	Milling machine, knee (Cincinnati Mill/Grind)	1952	20,162
U0382103	Milling machine, knee (Cincinnati Mill/Grind)	1953	20,162
U0568737	Milling machine, knee (Kearney, Trecker)	1955	24,058
U0568739	Milling machine, knee (Kearney, Trecker)	1955	24,058
U0568785	Milling machine, knee (Kearney, Trecker)	1955	22,855
U0207383	Milling machine, knee (Cincinnati Mill/Grind)	1952	21,062
U0207387	Milling machine, knee (Cincinnati Mill/Grind)	1952	21,062
U0382049	Milling machine, knee (Kearney, Trecker)	1953	24,140
U0382530	Milling machine, knee (Kearney, Trecker)	1953	24,140
U0260168	Milling machine, knee (Cincinnati Mill/Grind)	1951	21,925
U0568782	Milling machine, knee (Cincinnati Mill/Grind)	1955	28,748
U0382071	Milling machine, knee (Kearney, Trecker)	1953	26,503

Table 4-2. Government Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
U0382072	Milling machine, knee (Kearney, Trecker)	1953	26,505
U0568727	Milling machine, knee (Cincinnati Mill/Grind)	1955	30,143
U0568779	Milling machine, knee (Cincinnati Mill/Grind)	1955	30,143
U0568780	Milling machine, knee (Cincinnati Mill/Grind)	1955	30,143
U0568781	Milling machine, knee (Cincinnati Mill/Grind)	1955	30,143
U0427049	Milling machine, knee (Cincinnati Mill/Grind)	1952	27,368
U0382302	Milling machine, knee (Cincinnati Mill/Grind)	1953	23,846
U0382457	Milling machine, knee (Cincinnati Mill/Grind)	1953	23,845
U0568776	Milling machine, knee (Kearney, Trecker)	1955	34,952
U0384989	Milling machine, knee (Cincinnati Mill/Grind)	1953	26,848
U0385158	Milling machine, knee (Cincinnati Mill/Grind)	1954	26,848
U0334227	Milling machine, knee (Kearney, Trecker)	1952	24,996
U0258460	Milling machine, knee (Kearney, Trecker)	1953	23,992
U0126474	Milling machine, knee (Kearney, Trecker)	1953	21,775
U0208081	Milling machine, knee (Kearney, Trecker)	1953	22,240
U0257948	Milling machine, knee (Kearney, Trecker)	1952	26,323
U0240210	Milling machine, knee (Kearney, Trecker)	1952	22,149
U0350512	Milling machine, knee (Kearney, Trecker)	1952	22,149
U0382429	Milling machine, knee (Kearney, Trecker)	1953	22,149

Table 4-2. Government Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
U0382072	Milling machine, knee (Kearney, Trecker)	1953	26,505
U0568727	Milling machine, knee (Cincinnati Mill/Grind)	1955	30,143
U0568779	Milling machine, knee (Cincinnati Mill/Grind)	1955	30,143
U0568780	Milling machine, knee (Cincinnati Mill/Grind)	1955	30,143
U0568781	Milling machine, knee (Cincinnati Mill/Grind)	1955	30,143
U0427049	Milling machine, knee (Cincinnati Mill/Grind)	1952	27,368
U0382302	Milling machine, knee (Cincinnati Mill/Grind)	1953	23,846
U0382457	Milling machine, knee (Cincinnati Mill/Grind)	1953	23,845
U0568776	Milling machine, knee (Kearney, Trecker)	1955	34,952
U0384989	Milling machine, knee (Cincinnati Mill/Grind)	1953	26,848
U0385158	Milling machine, knee (Cincinnati Mill/Grind)	1954	26,848
U0334227	Milling machine, knee (Kearney, Trecker)	1952	24,996
U0258460	Milling machine, knee (Kearney, Trecker)	1953	23,922
U0126474	Milling machine, knee (Kearney, Trecker)	1953	21,775
U0208081	Milling machine, knee (Kearney, Trecker)	1953	22,240
U0257948	Milling machine, knee (Kearney, Trecker)	1952	26,323
U0240210	Milling machine, knee (Kearney, Trecker)	1952	22,149
U0350512	Milling machine, knee (Kearney, Trecker)	1952	22,149
U0382429	Milling machine, knee (Kearney, Trecker)	1953	22,149

Table 4-2. Government Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
U0283844	Milling machine, knee (Kearney, Trecker)	1953	23,420
U0293095	Milling machine, knee (Kearney, Trecker)	1952	30,700
U0350358	Milling machine, knee (Kearney, Trecker)	1952	28,615
U0130623	Milling machine, bed (Sundstrand)	1958	75,555
U0130595	Milling machine, bed (Sundstrand)	1958	71,554
U0504001	Milling machine, bed (Farrel)	1958	213,950
U0242566	Milling machine, bed (Kearney, Trecker)	1951	59,584
U0339496	Milling machine, bed (Allen)	1955	75,000
U0202210	Milling machine, bed (Cincinnati Mill/Grind)	1951	25,715
U0461001	Milling machine, bed (Cincinnati Mill/Grind)	1951	22,969
U0274567	Milling machine, bed (Cincinnati Mill/Grind)	1954	33,534
U0273700	Milling machine, bed (Cincinnati Mill/Grind)	1952	54,405
U0446234	Milling machine, bed (Cincinnati Mill/Grind)	1953	50,735
U0382167	Milling machine, bed (Cincinnati Mill/Grind)	1951	63,089
U0382172	Milling machine, bed (Cincinnati Mill/Grind)	1951	63,089
U0350367	Milling machine, bed (Cincinnati Mill/Grind)	1952	64,179
U0338938	Milling machine, profiling, horizontal spindle (Cincinnati Mill/Grind)	1960	227,115
U0210865	Milling machine, profiling, horizontal spindle Trv T, 36 IN (Pratt)	1953	29,843
U0130368	Milling machine, profiling, tape controlled (Giddings/Lewis)	1958	294,681

Table 4-2. Government Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
U0130311	Milling machine, profiling, horizontal spindle (Cincinnati Mill/Grind)	1958	202,269
U0569097	Milling machine, profiling (Kearney, Trecker)	1955	44,913
U0273721	Mill, bed, skin, vertical (Giddings/Lewis)	1952	220,478
U0275197	Mill, profile, skin (Cincinnati Mill/Grind)	1955	141,395
U0275198	Mill, profile, skin (Cincinnati Mill/Grind)	1955	145,025
U0130220	Mill, duplicate, skin, vertical (Kearney, Trecker)	1958	459,136
U0386952	Mill, profile, spar	1952	80,231
U0498231	Mill, profile, spar	1953	160,287
U0273716	Mill, profile, spar	1951	115,596
U0273724	Mill, profile, spar	1951	225,344
U0504010	Milling machine, profiling	1955	24,010
U0504011	Milling machine, profiling	1955	21,700
V2504098	Milling machine, profiling	0	24,104
U0338845	Mill router, vertical (Hufford)	1960	25,131
J06575486	Milling machine, miscellaneous	1967	26,844
U0362865	Planer openside	1951	34,820
U0354181	Planer openside (Rockford Tool)	1952	63,433
U0266775	Planer openside (Rockford Tool)	1952	58,119
U033890	Grinder, belt	1960	39,043

Table 4-3. Company-Owned Equipment to be Used at the Los Angeles Division

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0200608	Boring machine, horizontal (Giddings/Lewis)	1956	65,721
N0278254	Boring machine, horizontal (Giddings/Lewis)	1967	347,372
N0280605	Boring machine, jig, (Pratt)	1968	85,931
N0276117	Drilling machine, upright (Cleereman)	1967	33,959
N0276118	Drilling machine, upright (Cleereman)	1967	34,656
N0276142	Drilling machine, upright (Cleereman)	1967	35,705
N0280229	Drilling machine, upright (Pratt)	1968	35,266
N0274802	Drilling machine, upright (Cincinnati Lathe/Tool)	1965	30,716
N0274803	Drilling numerically controlled (Cincinnati Lathe/Tool)	1965	29,577
N0274804	Drilling machine, upright (Cincinnati Lathe/Tool)	1965	30,276
N0274805	Drilling machine, upright (Cincinnati Lathe/Tool)	1965	30,204
N0275332	Drilling machine, upright (Canedy Otto)	1965	32,785
N0218320	Drilling machine, radial (Fosdick)	1958	31,293
N0512324	Gear shaper (Fellows Gear)	1963	24,259
N0278218	Gear grinding machine (Frontier)	1968	99,496
N0217009	Grinding machine, Int Cy (Heald)	1957	31,351
N0217008	Grinding machine, Int	1958	40,435
N0279218	Grinding machine, surface (Blanchard)	1968	24,792
N0278336	Grinding machine, surface (Blanchard)	1967	24,123
N0279369	Grinding machine, T1/C1, (Ingersoll Mill Mac)	1968	27,573
N0274398	Lathe, heavy duty engine (Leblond, Rk Mach)	1964	21,849
N0276438	Lathe, turret (Bullard)	1967	323,897
N0213312	Lathe, turret	1957	32,005

Table 4-3. Company-Owned Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0216894	Lathe, turret (Jones/Lamson)	1957	20,188
N0218403	Lathe, turret (Jones/Lamson)	1958	22,639
N0216893	Lathe, turret (Jones/Lamson)	1957	21,389
N0218388	Lathe, turret	1959	26,584
N0218964	Lathe, turret (Warner Swasey)	1958	25,977
N0230273	Lathe, turret	1960	32,322
N0216899	Lathe, turret (Jones/Lamson)	1957	33,415
N0056196	Lathe, turret (Warner Swasey)	1942	29,750
N0056197	Lathe, turret (Warner Swasey)	1942	31,333
N0219179	Lathe, turret	1958	41,979
N0279376	Milling machine, knee	1968	32,175
N0224605	Milling knee horizontal plane (Cincinnati Mill/Grind)	1959	29,493
N0224611	Milling knee horizontal plane (Cincinnati Mill/Grind)	1959	29,402
N0205689	Milling machine, knee (Cincinnati Mill/Grind)	1956	23,433
N0216891	Milling machine, knee (Cincinnati Mill/Grind)	1958	22,591
N0217022	Milling machine, knee (Cincinnati Mill/Grind)	1957	28,082
N0205688	Milling machine, knee (Cincinnati Mill/Grind)	1956	30,625
N0216764	Milling machine, knee (Cincinnati Mill/Grind)	1957	32,459
N0224604	Milling machine, knee	1962	29,395
N0216763	Milling machine, knee (Cincinnati Mill/Grind)	1958	26,630
N0216768	Milling knee horizontal (Cincinnati Mill/Grind)	1958	33,066
N0205690	Milling machine, knee (Cincinnati Mill/Grind)	1956	30,958
N0216767	Milling machine, knee (Cincinnati Mill/Grind)	1957	33,366
N0277898	Milling machine, knee	1967	30,379
N0200404	Milling machine, knee (Cincinnati Mill/Grind)	1956	32,543

Table 4-3. Company-Owned Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0224164	Milling machine, knee (Cincinnati Mill/Grind)	1960	44,233
N0274399	Milling machine, knee (Kearney, Trecker)	1965	32,986
N0216889	Milling machine, knee (Cincinnati Mill/Grind)	1957	28,587
N0216890	Milling machine, knee (Cincinnati Mill/Grind)	1958	28,448
N0280609	Milling machine, knee (Cincinnati Mill/Grind)	1968	33,397
N0280610	Milling machine, knee (Cincinnati Mill/Grind)	1968	33,397
N0280611	Milling machine, knee (Cincinnati Mill/Grind)	1968	33,397
N0280612	Milling machine, knee (Cincinnati Mill/Grind)	1968	33,356
N0280613	Milling machine, knee (Cincinnati Mill/Grind)	1968	33,356
N0280614	Milling machine, knee (Cincinnati Mill/Grind)	1968	33,356
N0280615	Milling machine, knee (Cincinnati Mill/Grind)	1968	33,013
N0280616	Milling machine, knee (Cincinnati Mill/Grind)	1969	33,013
N0280617	Milling machine, knee (Cincinnati Mill/Grind)	1969	33,013
N0280618	Milling machine, knee (Cincinnati Mill/Grind)	1969	33,013
N0280619	Milling machine, knee (Cincinnati Mill/Grind)	1969	33,761
N0280620	Milling machine, knee (Cincinnati Mill/Grind)	1969	33,761
N0219181	Milling machine, knee (Kearney, Trecker)	1958	24,553
N0217101	Milling machine, knee (Kearney, Trecker)	1957	27,296
N0217103	Milling machine, knee (Kearney, Trecker)	1957	27,275

Table 4-3. Company-Owned Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0205706	Milling machine, knee (Kearney, Trecker)	1957	26,238
N0205707	Milling machine, knee (Kearney, Trecker)	1957	26,082
N0218363	Milling machine, knee (Kearney, Trecker)	1958	39,715
N0277384	Milling machine, knee (Kearney, Trecker)	1968	43,849
N0277385	Milling machine, knee (Kearney, Trecker)	1968	43,849
N0205705	Milling machine, knee (Kearney, Trecker)	1955	26,109
N0205708	Milling machine, knee (Kearney, Trecker)	1955	26,203
N0205709	Milling machine, knee (Kearney, Trecker)	1955	26,069
N0205710	Milling machine, knee (Kearney, Trecker)	1955	26,184
N0207656	Milling machine, knee (Kearney, Trecker)	1957	26,329
N0248182	Milling machine, knee (Kearney, Trecker)	1963	36,277
N0281978	Milling machine, knee (Kearney, Trecker)	1969	48,161
N0276067	Milling machine, knee (Kearney, Trecker)	1966	51,329
N0276068	Milling machine, knee (Kearney, Trecker)	1966	51,329
N0276069	Milling machine, knee (Kearney, Trecker)	1966	51,329
N0276073	Milling machine, knee (Kearney, Trecker)	1966	50,834
N0276070	Milling machine, bed (Cincinnati Mill/Grind)	1966	67,619
N0276071	Milling machine, bed (Cincinnati Mill/Grind)	1966	78,283
N0276072	Milling machine, bed (Cincinnati Mill/Grind)	1966	67,619

Table 4-3. Company-Owned Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0277541	Milling machine, bed (Cincinnati Mill/Grind)	1968	71,569
N0024246	Mill bed vertical	1948	343,721
N0277811	Milling machine, profiling 3-axis numerically controlled	1969	748,999
N0280984	Milling machine, profiling 3-spindle	1968	133,915
N0276062	Milling machine, profiling 3-spindle, horizontal 3-axis (Giddings/Lewis)	1968	888,764
N0276189	Milling machine, die sinking (Giddings/Lewis)	1966	333,945
N0276065	Milling machine, profiling 5-axes numerically controlled, 3 horizontal spindle	1968	1,124,034
N0278797	Milling machine, profiling 5-axes numerically controlled, 3 horizontal spindle	1968	676,367
N0200607	Milling machine, profiling horizontal traveling housing, 6'T, 1 spindle	1956	74,639
N0276179	Milling machine, horizontal	1968	1,016,317
N0276188	Milling machine, horizontal (Giddings/Lewis)	1968	825,958
N0275155	Mill contour profile (Wilson)	1965	124,247
N0277219	Milling machine, profiling 6 spindle, 3-axes tracer	1966	168,183
N0277411	Milling contour/duplicating (Wilson (Wilson)	1967	175,940
N0278198	Milling machine, profiling 3 spindle, 3-axes 144 in. x 30 in.	1968	159,192
N0278270	Milling machine (Wilson)	1968	151,910
N0280985	Milling machine, profile and duplicating	1968	133,915
N0280986	Milling machine, profile and duplicating	1968	135,752

Table 4-3. Company-Owned Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0278663	Milling machine, profiling (Onsrud)	1968	129,441
N0278664	Milling machine, profiling (Onsrud)	1968	129,441
N0278432	Milling machine, vertical (Kearney, Trecker)	1968	550,336
N0278433	Milling machine, vertical (Kearney, Trecker)	1968	550,336
N0278796	Milling machine, profile (Kearney, Trecker)	1968	519,706
N0278400	Milling machine, profiling (Wilson)	1968	290,001
N0281929	Milling machine (Cincinnati Mill/ Grind)	1969	71,550
N0276185	Milling machine, profiling (Wilson)	1966	117,069
N0278794	Machine, profiling (Cincinnati Mill/Grind)	1968	125,498
N0278581	Machine, profiling and duplicat- (Maschenen)	1967	23,892
N0278792	Milling machine, profiler (Onsrud)	1968	132,319
N0274533	Milling machine, profiling (Cincinnati Mill/Grind)	1967	992,449
N0276063	Milling machine, profiling (Cincinnati Mill/Grind)	1968	1,253,260
N0276064	Milling machine, profiling (Cincinnati Mill/Grind)	1968	1,212,154
N0276183	Milling machine, profiling (Cincinnati Mill/Grind)	1968	1,159,461
N0276184	Milling machine, profiling 4 vertical spindle	1968	1,137,310
N0274534	Milling machine, profiling 2 vertical spindle	1967	992,449
N0279205	Milling machine, profiling (Cincinnati Mill/Grind)	1968	1,154,606
N0276479	Milling machine, profiling (Cincinnati Mill/Grind)	1969	1,841,941

Table 4-3. Company-Owned Equipment to be Used at the Los Angeles Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0214260	Milling machine, die sinking (Kearney, Trecker)	1956	22,640
N0247971	Milling machine, die sinking (Kearney, Trecker)	1963	26,800
N0280575	Milling machine, die sinking (Kearney, Trecker)	1968	31,953
N0276702	Milling machine, router	1968	53,736
N0213333	Hone machine vertical	1957	44,881
N0248810	Saw, abrasive, high	1963	36,020
N0275205	Machine, ECM	1966	245,015
N0278793	Electro discharge machine (Cincinnati Mill/Grind)	1967	1,477,767
N0212758	Electro discharge machine (Elex Corp)	1956	23,429
N0277401	Edm machining system (Wadkin, Ltd)	1966	31,938
N0278231	Mill electric erosion (Anocut)	1967	154,054
N0277854	Erosion machine (Anocut)	1968	278,127
N0278288	Electro discharge machine (Cincinnati Mill/Grind)	1968	130,912
N0278289	Electro discharge machine (Cincinnati Mill/Grind)	1968	130,912
N0205690	Heat treat equipment	0	27,728
N0222071	Furnace box, electron	1959	75,834
N0270256	Heat treat equipment, electron	1963	32,369

Table 4-4. Company-Owned Equipment to be Used at the Tulsa Division

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0071767	Boring machine	1966	20,044
N1010093	Numerically controlled 2-axis jig borer	1968	50,242
N0260945	Grind machine	1967	75,017
N0261031	Grind machine	1967	26,004
N0260935	Lathe heavy duty engine	1966	24,262
N0261066	Lathe heavy duty engine	1967	25,522
N0261067	Lathe heavy duty engine	1967	31,194
N0632835	Lathe, turret	1965	35,245
N0261395	Milling machine	1969	25,051
N0775933	Milling machine	1968	29,254
N0785324	Milling machine	1967	116,201
N0785325	Milling machine	1967	116,489
N0785326	Milling machine	1968	116,159
N0785332	Milling machine	1968	312,687
N0785334	Milling machine	1968	116,330
N0785335	Milling machine	1968	116,330
N0785350	Milling machine	1967	136,457
N0785653	Milling machine	1968	146,369
N0786126	Milling machine	1968	385,550
N0786127	Milling machine	1968	385,550
N0831732	Milling machine	1969	27,381
N1010540	Milling machine	1969	91,213
N0216766	Milling machine, knee	1957	24,055
N0216898	Milling machine, knee	1958	36,124
N0247168	Milling machine, knee	1962	40,157
N0260950	Milling machine, ram	1968	33,469
N0785331	Milling machine, profiling	1968	298,617
N0785475	Machine, profiling	1967	115,658
N0785476	Machine, profiling	1967	116,720
N1010296	Machine, profiling	1969	130,761
N1010297	Machine, profiling	1969	130,761
N1010298	Machine, profiling	1969	129,001
N1010299	Machine, profiling	1969	129,011
N1010300	Machine, profiling	1969	129,011
N1010301	Machine, profiling	1969	126,472
N1010718	Machine, profiling	1967	31,478

Table 4-4. Company-Owned Equipment to be Used at the Tulsa Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0785338	Machine, profiling	1967	31,478
N0824907	Machine, profiling	1967	138,444
N0261293	Machine, profiling	1968	24,490
N0709821	Machine, profiling	1966	53,467
N0639399	Planer, openside	1968	119,396

Table 4-5. Company-Owned Equipment to be Used at the Columbus Division

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0829999	Boring machine (Devlieg)	1969	116,189
N0830595	Boring machine (Devlieg)	1969	113,490
N0824656	Boring machine, jig (Pratt)	1968	155,366
N0824657	Boring machine, jig (Pratt)	1968	155,366
N0821692	Drilling machine (Pratt)	1966	27,773
N0821693	Drilling machine, multiple spindle numerically controlled (Pratt)	1967	32,658
N0824648	Drilling machine, multiple spindle numerically controlled (Pratt)	1967	32,658
N0820879	Grind machine	1965	23,924
N0822925	Grind machine	1967	23,885
N0822926	Grind machine	1967	23,885
N0822940	Grind machine (Cincinnati Mill/ Grind)	1967	34,801
N0822223	Grind machine, floor (Heald)	1966	25,038
N0820882	Grind machine, floor (Landis)	1966	22,717
N0826945	Lathe	1969	149,823
N0830046	Lathe	1968	28,036
N0830353	Milling machine	1969	22,068
N0803045	Milling machine	1959	61,541
N0831731	Milling machine, (Cincinnati Mill/ Grind)	1969	27,381
N0831732	Milling machine (Cincinnati Mill/ Grind)	1969	27,381
N0829954	Milling machine, ram (Cincinnati Mill/Grind)	1969	21,188
N0839955	Milling machine, ram (Cincinnati Mill/Grind)	1969	21,188
N0821817	Milling machine, profiling, numerically controlled	1968	523,250
N0821818	Milling machine, profiling, horizontal spindle (Giddings/Lewis)	1969	523,250
N0821819	Milling machine, profiling, horizontal spindle (Giddings/Lewis)	1969	523,250
N821963	Milling machine, profiling, 4-spindle 4-axis contour (Pratt)	1968	610,937

Table 4-5. Company-Owned Equipment to be Used at the Columbus Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0276190	Milling machine, profiling, horizontal numerically controlled, 3-axes single spindle (Giddings/ Lewis)	1966	308,455
N0822979	Milling machine, profiling, numerically controlled, horizontal spindle, drill and bore (Kearney, Trecker)	1967	144,471
N0824905	Milling machine, profiling vertical hydro tel, 30 series	1967	138,444
N0824906	Milling machine, profiling vertical hydro tel, 30 series	1967	138,444
N0824907	Milling machine, profiling vertical hydro tel, 30 series	1967	138,444
N0834904	Milling machine, profiling vertical hydro tel, single spindle	1968	138,444
N0821805	Milling machine, profiling vertical numerically controlled	1966	56,116
N0821806	Milling machine, profiling vertical numerically controlled	1966	56,116
N0821809	Milling machine, profiling vertical numerically controlled	1967	56,116
N0821810	Milling machine, profiling vertical numerically controlled	1967	56,116
N0821807	Milling machine, profiling vertical numerically controlled	1967	56,116
N0821808	Milling machine, profiling vertical numerically controlled	1967	56,116
N0821811	Milling machine, profiling numerically controlled vertical single spindle	1967	80,300
N0821812	Milling machine, profiling numerically controlled vertical single spindle	1967	80,300
N0821813	Milling machine, profiling numerically controlled vertical single spindle	1967	80,300

Table 4-5. Company-Owned Equipment to be Used at the Columbus Division (Cont)

Inventory	Facility Description	Date of Manufacture	Acquisition Cost ($)
N0821814	Milling machine, profiling numerically controlled vertical single spindle	1967	80,300
N0821815	Milling machine, profiling numerically controlled vertical single spindle	1967	80,300
N0821816	Milling machine, profiling numerically controlled vertical single spindle	1967	80,300
N0830351	Milling machine, profiling numerically controlled vertical single spindle	1969	81,991
N0830352	Milling machine, profiling numerically controlled vertical single spindle	1969	81,991
N0821926	Milling machine, traveling housing (Kearney, Trecker)	1966	252,330
N0821927	Milling machine, traveling housing (Kearney, Trecker)	1966	252,330
N0831928	Milling machine, traveling housing (Kearney, Trecker)	1967	252,330
N0821964	Milling machine, traveling housing (Kearney, Trecker)	1967	377,323
N0830421	Heat treating equipment	1969	57,296
N0825646	Heat treating furnace	1968	32,593
N0802950	Heat treating furnace	1959	161,725
N0817943	Metal finish equipment	1965	23,922
N0803082	Metal process tank	1959	58,549

Table 4-6. Major Equipment Required for Operations at KSC

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Maintenance and checkout of boosters and orbiters.	M&C equipment.	$ 8,000,000	New - VAB	
Launch control.	Instrumentation and equipment, LCC.	$ 4,900,000	New - LC39 LCC	
Flight crew training.	Flight simulation equipment.	$35,000,000	New - KSC industrial area.	
Level II engine overhaul.	Engine overhaul platforms, dollies, and equipment.	$ 1,000,000	New - VAB	
Tracking.	Radars.	$ 2,000,000	New - ETR	
Augment existing laboratories to shuttle program.	Miscellaneous laboratory and test equipment.	$ 1,000,000	New - KSC	
Pressurant supply and storage for launch complex.	Converter/compressor facility GN_2 and GH_e.	None.	Available at LC39.	
Assembly and transport platform/ umbilical tower.	Mobile launchers (3)	Major modification (2) $10,600,000	Available.	1 Unit remains for Saturn V.
Move mobile launchers to launch pads.	Crawler/transporter.	None.	Available.	
Propellant supply and storage for launch complex; NASA. Available.	LH_2 and LO_2 ready storage and transfer.	Add 850,000 gal. LH_2. Add LO_2 boil-off tank. ($ 4,600,000)	Add to LC-39	

Table 4-6. Major Equipment Required for Operations at KSC (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Control landings.	Landing facility control equipment.	($500, 000)	New on Meritt Island or at CKAFS.	
Tow vehicles from VAB to LC39A and B and from airstrip to VAB.	Tow tugs (3)	($500, 000)	New	

Table 4-7. Major Equipment Required for Cluster Firing at KSC

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Provide static firing stand for orbiter during cluster firing and flight readiness firing.	1. Mobile launcher (ML).	Install steel support tower. Provide and install 2 water jacketed diffuser nozzles. Modify Firex System. Modify - augment operational GSE for cluster firing. Modify umbilical arms Major modifications = $3,250,000 Cost to operational ML.		
Install test article on mobile launcher.	VAB cranes.	No modification required.		
Transport Test Article from Seal Beach to KSC.	AKD Point Barrow.	No modification required.		
Transport Test Article.	S-II type transporter.	$50,000 modification.		

Table 4-8. Major Equipment Required for Human Factors (Zero-G) at Edwards AFB

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Zero-g test verification of systems.	NASA - KC-135	TBD.	NASA, F.R. 6, Edwards AFB.	
			TBD.	
Perform flight test on ABES and selected avionics.	B-52 Flying Test Bed.	TBD.	Edwards AFB.	

Table 4-9. Major Equipment Required for Thermal Control Systems at NASA, Houston

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Transport large composite vehicle sections from Long Beach to Houston.	Super Guppy.	No modification required.		
Transport to and from airport.	Commercial truck.			

Table 4-10. Major Equipment Required for Laboratory Testing at Downey

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
ENVIRONMENTAL TESTING – DOWNEY				
Climatics Laboratory.	3 Thermal altitude chambers to 200,000 ft; -100 to 350 F; 8-by-8-by-7 ft.		Building 288.	
	3 Corrosive contaminants, oxygen and humidity chambers to 200,000 ft; -100 to 350 F; 95 percent relative humidity; size 4-by-4-by-4 ft.		Building 288.	
	3 High temperature chambers to 1200 F; Size 1-1/2-by-1-1/2-by-1-1/2 ft.		Building 288.	
	4 High-low temperature chambers; -120 to 350 F; Size 3-by-3-by-3 ft.		Building 288.	
	5 Humidity chambers; -120 to 250 F; to 100 percent relative humidity; size 6-by-6-by-4 ft.		Building 288.	
	2 Salt spray cabinets; 125 F; Size 4-by-4-by-6 ft.		Building 288.	
Climatics laboratory.	Weatherometer chamber; -100 to 200 F; 20 percent to 90 percent relative humidity; 3 to 5-in. rain.		Building 288.	
	Explosive and flammability chamber; positive or negative pressure; 3-by-5 ft.		Building 288.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
	Salt water immersion system; 3-by-2-by-4 ft.		Building 288.	
Thermal Test.	Infrared radiant heating ovens to 5500 F; 36 stationary and several portable channels for closed-loop programming of heater output.		Building 288.	
Thermal Test.	Plasma simulation chambers to 4-by-5 ft; spin stabilized arc to 3000 Amp and 26, 500 Btu/lb. Plasma flows to mach 3.		Building 56	
	Convective tunnel heating system with 2000 F gas flows at 1 lb/sec.		Building 56.	
Thermal Test.	Measuring instruments - local total enthalphy probe (entrance area of 0.090 in.) streak cameras; thermal-sensing-device testers (to 6300 F).		Building 56.	
Space simulation.	3 Space simulation chambers; 6-by-14 ft; oil diffusion pumped; atmospheres to 1×10^{-7} Torr; 80 to 100 percent cryoshrouded (-350 F); solar simulators to 2 solar constants.		Building 288.	
	2 Vacuum bell jar systems, 18-by-30 in.; oil diffusion pumped, atmospheres to 1×10^{-7} Torr.		Building 288.	
	6 Ultra-high vacuum space simulation chambers to 18-by-30 in.; ion pumped; 100 percent cryoshrouded; bakeable at 450 C; minimum pressure 5×10^{-9} Torr.		Building 288.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Space simulation.	Ultra-high vacuum environmental test chamber; 5-by-6 ft; 100 percent cryo-shrouded; minimum pressure 2×10^{-11} Torr; ion pumped; quadruple residual gas analyzer.		Building 288.	
Dynamics acoustic.	1 quiet room, 1728 ft^3.		Building 288.	
	2 Reverberant Chambers, 164 dB SPL; 190 ft^3.		Building 288.	
Acceleration and shock.	2 Centrifuges to 250 g's; 34 in. radius.		Building 288.	
	3 Shock machines to 3000 G's, 3 ms to 15 ms duration.		Building 288.	
Data.	14 Tape recorders, 1/4 to 1 in. tape 2 to 14 channels.		Building 288.	
Data.	Spectrum analyzers.		Building 288.	
	Oscillographs, X-Y plotters, bandpass filters, etc.			
Dynamics testing vibration.	9 Vibration exciters; 10,000 force-lb.		Building 288.	
	4 Vibration exciters; 30,000 force-lb.		Building 288.	
	6 Vibration thrusters; 10,000 force-lb.		Building 288.	
	2 Hydraulic shakers; 100,000 force-lb.		Building 288.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
	7 Power amplifiers; 15 - 175 kw output; 20 to 40 kw output.		Building 288.	
	5 Random equalizers, automatic 10- to 2000-Hz control.		Building 288.	
	11 Slip oil film tables, granite and steel to 96 ft by 96 in.		Building 288.	
MECHANICAL AND FLUID SYSTEMS TESTING – DOWNEY				
Structural testing - facilities.	Structural test floor; 60-by-180 ft with floor beams at 4 ft centers.		Building 288.	
Structural testing - facilities.	Structural test tower; 20-by-104 ft static thrust loads to 500,000 lb.		Building 450.	
Structural testing - facilities.	Structural test tower; 140 ft high, 75 ft sides. Floor reacts to thrust loads of 1×10^{-7} lb. Tower resists bending movements of 5×10^{-8} inches and shears up to 4×10^{-5} lb.		Seal Beach	
Structural testing - hydraulic.	400 cylinders (tension and compression), 500 lb to 500,000 lb.		Building 288.	
	10 pumps from 3 gpm at 5000 psig to 20 gpm at 5000 psig.		Building 288.	
	15 Multiple-pressure, static dynamic load maintainers - 6 with ten channels each 9 with six channels each.		Building 288.	
	2 Overhead cranes, 5-ton capacity, 35-ft hook height.		Building 288.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Structural testing - instrumentation.	130 Load cells, capacities from 200 lb to 300,000 lb from 0.5 in. to 150 in. full scale.		Building 288.	
	400 deflection transducers.		Building 288.	
	12 CSC strain recorders, 100 channels each.		Building 288.	
	4 Select high speed digital recorder systems, 200 channels each.		Building 288.	
	3 Data technical digital recorders, 40 channels each.		Building 288.	
	Bridges, potentiometers, meggers, decade resistance units, precision calibrators, BLH indicators, etc.		Building 288.	
	Closed circuit television at all sites.		Building 288.	
Liquid propellant and cryogenic testing.	2 Combustible gas detectors, 10- and 5-channels.		Building 286.	
	2 Compressors and accumulators, 10,000 psig.			
	Pressure accumulator, 44.3 cubic feet at 4600 psig.			
	5 Liquid hydrogen dewars, 250 gal.			
	Dewar, 2500 gal.			
	Liquid nitrogen dewar, 5,000 gal.			

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Liquid propellant and cryogenic testing.	Vacuum system, 4-by-5 ft chamber 10^{-6} Torr, vacuum pump 300 cfm from ambient to 10^{-3} Torr. 2 Leak detectors 10^{-3} to 10^{-7} atmospheres cc/sec. Residual gas analyzer and micro-manometer, electrohydraulic slosh and vortex shaker system; 20,000 force-lb vector; 0 to 8 in. double amplitude; dc to 20 cps; sine wave; maximum of 5 g's with 4000 lb load at 10 cps.		Building 286.	
Liquid propellant and cryogenic testing.	Gravidrome - zero G; 100 ft high with free fall time of 2.1 second includes edihydrogoniometer, rotating-cylinder viscometer, laser source and high speed recorder. Reaction control system, four test cells, decontamination, cleaning, assembly, instrumentation and control rooms. Normally facilitized for nitrogen tetroxide, monomethyl hydrazine, and UDMH/ hydrazine. Modifications and cost to be determined.		Building 450.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Environmental control.	Altitude chamber, 15-by-18 ft; 1 x 10^{-6} Torr; launch profile to 100,000 ft; man-rated. Clean room, 60-by-40 ft; filtered air to 160,000. Whitfield bench, filtered air to 100,000. 5 water/glycol closed-loop circulating units. Chiller unit, two-stage; -20 F and -60 F at 5000 Btu/hr. Constant temperature bath, low-temperature circulating system. 2 aircraft hydraulic test stands, 10 and 40 gpm; temperature controlled; 5000 psig. 6 hydraulic power supplies, 10 - 20 gpm pumping capacity. 2 hydraulic power stands, 1/10 gpm; 30,000 psig. Hydraulic pressure booster, 100 to 80,000 psig at 1/10 gpm. Hydrapulse tester, 5 gpm; 5000 psig in 1 sec.		Building 288.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Fluid systems.	Air compressor, 3000 psi. Pneumatic booster, 15,000 psi; helium or gaseous nitrogen. Pneumatic booster, 20 scfm at 20,000 psig. 347 pneumatic receivers, 20, 10, 5, and 8.6 cubic feet each; 5000, 20,000, and 1800 psig. 2 filters, 5 micron at 10,000 and 5000 psig. 2 heat exchangers, 750 F at 4000 psig and -320 F at 4000 psig. 2 helium recovery bags, 25,000 scf total; 6-in. water. Helium purifier, 70 scfm; 3500 psig. Flow control unit, 20 lb/sec. 4 High-pressure test cells, one equipped as clean room. Ullage tank, 2500 cubic feet; 60 psig. Catch tank, 3000 cubic feet. Liquid-nitrogen dewar, 14,000 gal. Gas Generator, 10,000 psig.		Building 299.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Mechanical systems.	Pneumatic struts, nitrogen bottle pressure to 2000 psi. CDC leak detector, helium to 10^{-11} cc/sec. Beckman hydrocarbon analyzer.		Building 288.	
ELECTRONIC SYSTEMS TESTING				
Electrical.	Fuel cell test complex; 3 cells, data acquisition and evaluation at ambient to 10^{-6} Torr. Continuity Scanner, scans 50 to 250 points in 2 sec. 2 Inverter testers, 1500 and 500 watt; 28 vdc to 3 phase 400 Hz. 2 Gas analyzers, continuous air analysis up to LEL of combustible gases. 2 Sonic spectrum analyzers, random and discrete analysis, 5 Hz to 22.5 kHz. 2 Variable frequency generators, 50 to 1800 Hz. Load banks, 3 kw and 350 amp. Arc resistance tester, insulation tests to ASTM D 495-56.		Building 288.	
Electronics.	2 RF shielded enclosures, 16-by-52 ft. 2 Screen rooms, 12-by-15 ft.		Building 001.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Electronics.	Data acquisition system, 400 channels.		Building 001.	
Instrumentation.	Digital data acquisition system, 400 channels of strain-gauge plus 400 channels thermocouple junctions.		Building 288.	
	41 Oscillographs, 18 to 36 channels, 5000 cps at speeds of 0.25 to 64 ips and 1.6 to 100 imps.			
	6 dynographs, 8 channels to 100 cps at speeds of 0.1 mm/sec. to 25 cm/sec.			
	4 magnetic-tape recorder-reproducers, 14 channels, 100 kHz, 0.1 to 10-v rms.			
	Digital data system, 40 channels with signal conditioning, 120 channels available.			
	2 digital data systems, 100-channel systems.			
Electromechanical.	17 temperature chambers, 1 to 9 cubic feet, -320 to 2500 F.		Building 288.	
	11 temperature baths, -300 to 1200 F.			
	2 fluid system proof pressure chambers, 20,000 to 10,000 psi.			
	4 vacuum test systems, 3-1/2-by-5 ft; 10^{-9} Torr.			

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Electromechanical.	7 pressure calibration systems and standards, 0 to 10,000 psig. 1 vibration calibration test system, 0 to 0.375 in.; 1 to 3000 cps; 30 g's. 8 acceleration/angular display test systems. 4 clean test areas and laminar flow benches. 2 leak-detection systems. 1 dynamometer, 100 in.-lb.		Building 288.	
MATERIALS AND PROCESSES TESTING – DOWNEY				
Materials development.	2 fatigue testers, maximum loading capability, 500 lb to 10,000 lb. Creep frames, 10,000 lb. X-ray diffraction equipment. Pyrometer, optical, 2 colors. Emission spectroscopy equipment. Gas chromatographic. Ultraviolet, infrared and atomic adsorption spectrophotometric equipment. Thermal conductivity, emissivity and diffusivity equipment. Flammability test equipment.		Building 004.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Materials development.	Leak detection equipment. Mechanical property test machines. Integrated mechanical property test system. Mechanical property biaxial test system. Metallographic equipment. Electro-optical strain measurement systems.		Building 004.	
Process development.	Longitudinal positioner, fusion welding. 3 fusion welding machines, ac/dc. Rotary positioner. 2 metallographs. 2 rubber mills. 2 spotwelders. 2 spotwelders, capacitor discharge. Percussion stud welder. Welding station. Welding system, percussive arc and TIG skate. 4 hydraulic presses. 3 ovens, 150 cubic feet, 500 F; 15 cubic feet, 1500 F.		Building 004.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Process development.	Vacuum form, platen. Autoclave clamshell, 6 ft by 20 in.; 250 psi and 800 F. Autoclave tube, 3 by 8 ft. Platen hydraulic press.		Building 004.	
LABORATORY SUPPORT TESTING – DOWNEY				
Support services laboratory.	7 mills, 10-by-22 in. to 12-by-30 in.; one with tracer. 9 lathes, 10 to 20 inch; one with 2/1000 to 1/8 capability and pressure-sensing device. Shaper, 36 in. 12 drill presses. 3 belt sanders. 9 welding machines. Tool grinders, power hack saws, power brake, shears, punches, band saws, hoists.		Building 288.	
DATA REDUCTION LABORATORY – DOWNEY				
Data Processing.	2 stored program decommutators and associate MUX and AID converters. 2 FR600, Ampex analog record/play back. 1 FR1400, Ampex analog record/play back.		Building 006.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Data Processing.	36 Discriminators. 1 timing system, elapsed time code. 2 tape search and control. 30 digital analog converters. 2 oscillograms. 2 SDS 920 computers. 2 tape control units. 1 format control buffer. 2 printer/plotter and associate memory and electronics. 2 16-Track CP 200 digital tape units. 1 Switching matrix computer and manual control. 1 line printer. 1 off-line coupler. 1 magnetic tape controller. 1 magnetic tape transporter. 1 program switching unit. 8 digital tape units.		Building 006.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
ANTENNA TESTING – DOWNEY				
Communications and antenna testing.	Oscillator, microwave, Model 814A-C-1 LFE. Platform, hydraulic lift. Tower, antenna (40 ft). Tower, antenna (40 ft). Oscillator, microwave, Model 814A-S-2 LFE. Oscillator, microwave, Model 814A-X-21 LFE. Address storage unit, Model 610B, Scientific Atlanta. Tower, antenna (40 ft). System, antenna pattern, A-106-1-T-19. Recorder, rectangular, Model APR-22C, Scientific Atlanta. Generator, remote tuner, Model SS-21-SLA, Scientific Atlanta. Converter, Model AP1130, Scientific Atlanta. Tower, antenna, Model MT416-R, Scientific Atlanta. Receiver, Model 402-SLA, Scientific Atlanta. Receiver, Model 1602, Scientific Atlanta.		Downey. Available.	

Table 4-10. Major Equipment Required for Laboratory Testing at Downey (Cont)

Task	Equipment Name/Description	Modifications/ Cost	Location/Status	Remarks
Communications and antenna testing.	Printer, Model 1801, Scientific Atlanta. Tower, antenna, Model 5822B-R NL-5, Scientific Atlanta. Positioner, antenna, Model 5323-7B-16R. Receiver, Model 1640, Scientific Atlanta. Recorder, rectangular, Model 1520, Scientific Atlanta. Printer, Model 1803, Scientific Atlanta. Punch, paper tape, Model 1863. Tower, Model 5872-R-NL, Scientific Atlanta. Positioner, Model 5330A-7B-16R, Scientific Atlanta. Reader, paper tape, Model 1882, Scientific Atlanta.		Downey. Available.	

5.0 MAJOR TEST EQUIPMENT AND GSE

5.0 MAJOR TEST EQUIPMENT AND GSE

Major test equipment and GSE to be furnished by the government consists of items for handling of the assemblies during fabrication, assembly, final assembly, and checkout. In addition, equipment required for checkout at the system level and integrated checkout in the final assembly station is included. Development testing requires specialized pieces of equipment in the various laboratories discussed previously in Section 2.3. A preliminary list of this equipment is given in Table 5-1.

Table 5-1. Major Items of Operations Site GSE

Description	Handling	Maintenance and Refurbishment	Checkout	Ground Test Operations	Estimated Cost
1. Crew egress vehicle	C			X	
2. Tow tractor	C	C		X	
3. Tow bar nose gear	X			X	
4. Tie-down cables - wheel chocks	X	X		X	
5. Engine access stands (air-breathing and rocket) 1 set each	X	X	X		
6. Control surface stands	X			X	
7. Ground crew access	X			O, B	
8. Platforms - data removal	X			X	
9. Passenger egress vehicle	O				
10. Protected passenger transportation (to/from orbiter)(bus)	C			C	
11. Payload removal load bar and equipment (emergency)					
12. Vehicle external cleaning stands (equipment)		X			
13. Access panel removal - wing - work stand		X			

Legend
B = Booster GSE
O = Orbiter GSE
C = Common design for booster and orbiter
X = Common with different design for booster/orbiter

Table 5-1. Major Items of Operations Site GSE (Cont)

Description	Handling	Maintenance and Refurbishment	Checkout	Ground Test Operations	Estimated Cost
14. Access Panel removal - fuse (work stand)		X			
15. Canard - left- and right-hand (work stand)		X			
16. Fuselage- side left- and right-hand (work/stand)		X			
17. Wheel well access (main landing gear) (work/stand)		X			
18. Nose stand (work/stand)		X			
19. Nose gear area access stand (work/stand)		X			
20. Wing access (various) (work/stand)		X			
21. Cockpit access stand (work/stand)		X			
22. Mating area access stands (horizontal)(work/stand)	X	X			
23. Vertical rudder access stand (work/stand)		X			
24. Rocket engine sling		X			
25. Airbreathing engine sling		X			
26. Engine removal/install fixture (airbreathing)		X			
27. Rocket engine removal/install fixture		X			
28. Rudder removal/install load beam and sling		X			
29. Wing handling load beam and sling		X			
30. Wing "movable surface" handling fixtures (flaps, spoilers, etc.)		X			
31. Radome removal/install stand		X			
32. APU removal/install fixture		X			

Legend
B = Booster GSE C = Common design for booster and orbiter
O = Orbiter GSE X = Common with different design for booster/orbiter

Table 5-1. Major Items of Operations Site GSE (Cont)

Description	Handling	Maintenance and Refurbishment	Checkout	Ground Test Operations	Estimated Cost
33. Engine cowling cradle (air-breathing)		X			
34. Rocket engine transportation dollies		X			
35. "Airbreathing" engine transportation dollies		X			
36. Radome holding fixture		X			
37. Control surface protractors		X			
38. Wing transportation dolly		X			
39. Rudder transportation dolly		X			
40. ACS removal/install fixtures and slings		X			
41. Pivot and support adapter	B, O				
42. Vehicle lift sling	X				
43. Riseoff disconnect panels (launcher)	X				
44. Canard transportation dolly		X			
45. Canard remove/install load beam		X			
46. Generator test stand		X			
47. Blast deflectors (for fuselage protection during engine run-up)		X			
48. Jet-engine starting cart		X			
49. Sets of rigging pins and safety locks		X			
50. Battery handling install/remove	X	X			
51. Cleaning units (vacuum)		X			
52. Nose landing gear trunnion shaft puller		X			
53. Main landing gear trunnion shaft puller		X			

Legend
B = Booster GSE
O = Orbiter GSE
C = Common design for booster and orbiter
X = Common with different design for booster/orbiter

Table 5-1. Major Items of Operations Site GSE (Cont)

Description	Handling	Maintenance and Refurbishment	Checkout	Ground Test Operations	Estimated Cost
54. Brake handling fixture (nose gear and main landing gear)		X			
55. "Airbreathing" engine maintenance stand		X			
56. "Airbreathing" engine test stand silencer		X			
57. Nose landing gear removal dollies		X			
58. Main landing gear removal dollies		X			
59. Generator sling		X			
60. Tripod jacks - vehicle (for wing pickup)		X			
61. Tripod jacks - vehicle (for fuselage pickup		X			
62. Tripod jacks - vehicle (for axle handling pickup)		X			
63. Thrust ring removal and handling sling		X			
64. Hand tools - special design - set	X	X			
65. Payload area access stand (installed with crane)	O	O		O	
66. Payload door access stands left-hand and right-hand	O	O		O	
67. Payload area access stand load bar and sling	O	O		O	
68. Payload weighing and balancing fixture	O	O			
69. Payload install/remove GSE slings	O	O		O	
70. Payload guide rails install/ remove	O	O		O	
71. Payload handling load beam vertical and horizontal	O	O		O	

Legend
B = Booster GSE C = Common design for booster and orbiter
O = Orbiter GSE X = Common with different design for booster/orbiter

Table 5-1. Major Items of Operations Site GSE (Cont)

Description	Handling	Maintenance and Refurbishment	Checkout	Ground Test Operations	Estimated Cost
72. Payload transportation cart	O	O		O	
73. Payload storage stand	O	O		O	
74. Payload work stands	O	O		O	
75. Payload door removal/install align	O	O		O	
76. Payload door transport cart	O	O		O	
77. Payload door storage cart	O	O		O	
78. Payload air lock test device	O	O		O	
79. Master tooling GSE - interface control payload/orbiter/dock module	O	O			
80. SSV lift and rotate sling	X				
85. Umbilical tower	C				
86. Swing arms	C				
87. Crawler-transporter	C				
88. Crane umbilical tower	C				
89. Emergency egress system				C	
90. Erection tag line and winch	X, C				
91. Vertical mate access platforms	C				
92. Vertical lift-mobile load beam (install in VAB)	C				
93. Hydraulic ground power unit	C	C	C	C	
94. Air conditioning unit		C	C		
95. Chilled water/glycol unit		C	C		
96.					
97. Pneumatic control cart					
98. Hydraulic valve test stand		C			
99. Hydraulic pump and motor test stand		C			
100. Servo-valve test stand		C			
101. Gaseous helium service units					
102. Chilled water and glycol serving					

Legend
B = Booster GSE C = Common design for booster and orbiter
O = Orbiter GSE X = Common with different design for booster/orbiter

Table 5-1. Major Items of Operations Site GSE (Cont)

Description	Handling	Maintenance and Refurbishment	Checkout	Ground Test Operations	Estimated Cost
103. Hydraulic service units (4000 psi)					
104. Air conditioning units (for cabin, fuselage)					
105. APU test stand					
106. Water/glycol unit (umbilical tower)	C		C	C	
107. ECS (environmental control system) unit at launcher					
108. Pneumatic control unit at launcher					
109.					
110. Flex-connections for tank pressurization					
111. GN_2 purge hose kit	X				
112. GH_2 burn stack	O				
113. GN_2 storage	C				
114. LH_2 tank truck	C				
115. Gaseous helium storage (for pressurization of tanks)	C, X				
116. Defueling pit and connections					
117. GH_2 service units					
118. Fuel and propellant tank pressurization tester	C				
119. Gaseous helium service units	O				
120. Umbilical disconnects					
121. Defueling - ground connection cables					
122. Electrical power cart	C	C	C	C	
123. Line replaceable unit test station		X			
124. Set of cables and adapter for line replaceable unit		X			
125. Universal test equipment		X	X	X	

Legend
B = Booster GSE
O = Orbiter GSE
C = Common design for booster and orbiter
X = Common with different design for booster/orbiter

Handling equipment required during manufacture of the orbiter vehicle includes the following items:

Nose Assembly

- Panel lifting sling
- Portable-tank tent
- Support workstand

Forward Fuselage

- Support workstand

Crew Module

- Lifting sling assembly
- Support workstand
- Escape-hatch lifting sling
- Airlock-hatch lifting sling

Intermediate Fuselage

- Horizontal-payload lifting sling
- Support workstand
- LO_2 tank transfer dolly

LO_2 Tank

- Tank lifting sling assembly
- Rotation dolly

Surfaces and Doors

- Radiator support stand
- Payload down lifting assembly
- Elevon support stand
- Wing access stand
- Access panel storage rack
- Vertical stabilizer access (Vertical)
- Vertical stabilizer workstand (Horizontal)
- Vertical stabilizer lifting sling

Aft Fuselage

Support workstand
Lifting sling assembly
Portable task tent
Engine access (Horizontal)
Engine transfer dolly (Horizontal)
Engine lifting sling

Final Assembly

General access and workstands
TPS panel racks
TPS panel slings
Leading edge lifting sling
Landing gear support dolly
Vehicle jack set
Air-breathing engine sling
OMS tank lifting sling
OMS tank support stand
Orbiter surface transporter

LH_2 Tank

Aft bulkhead gore dolly
Aft bulkhead assembly dolly
Forward bulkhead assembly dolly
Vacuum cup sling
Tank dolly
Aft skirt assembly sling
Forward skirt assembly sling

Equipment required for development testing includes the following items, grouped by system:

Data Control and Management

Simulation language (Simulation Laboratory)

Control and data acquisition computer (Avionics Systems Integration Laboratory, ASIL).

Utility software (ASIL).

Cooling system (ASIL).

Electrical power (ASIL).

Power Generation

LH_2 and LO_2 facility supply (Cryogenics Laboratory, Fuel Cell Laboratory, Power Generation and Hot Fire Laboratory, CL, FCL, and PGHL).

Data acquisition system (CL, FCL, and PGHL).

H_2 recovery or burn system (CL).

APU exhaust-handling system (PGHL).

Control computer and test programs (CL, FCL and PGHL).

Simulated reactant supply System (FCL).

Programmable electric load (FCL and PGHL).

Programmable hydraulic load (PGHL).

Blockhouse deflectors, etc., to support hotfire of APU turbines (PGHL).

Electrical Power Distribution and Control

Control and data acquisition console (integration with both avionic and nonavionic loads).

Power sources (avionics integration).

Cooling (avionics integration).

Actual or simulated nonavionic loads (example: ABES, starters).

Hydraulic Power

Programmable loads for actuators (Hydraulic Controls Laboratory).

Control and data acquisition console (Hydraulic Controls Laboratory and Avionics-Hydraulics Integration Laboratory).

Electric motor drives for hydraulic pumps (Hydraulic Controls Laboratory).

Structure for support of hydraulic system (Hydraulic Controls Laboratory).

Equipment for interface of Avionics Integration Laboratory with Hydraulic Controls Laboratory).

Guidance Navigation and Control

Power source.

Simulators (servo drivers).

Computer and software.

Cooling system.

Data acquisition system.

Gimbal table.

Displays and Controls (D&C)

Power (D&C Human Factors Laboratory).

Communications, voice (D&C Human Factors Laboratory).

Control and data acquisition console (integration with other elements of avionics and vehicle D&C Integration Laboratory).

Power sources (D&C Integration Laboratory).

Cooling for equipment and personnel (D&C Integration Laboratory).

Simulated external visual presentations (D&C Integration Laboratory).

Computer simulation programs of non-avionic subsystems (D&C Integration Laboratory).

Communications

Power (Subsystem Integration Laboratory and Avionic Integration Laboratory (SSIL and AIL).

Heat sinks (SSIL and AIL).

Simulated voice and data sources (SSIL and AIL).

Test control and data acquisition console (SSIL and AIL).

Stimuli equipment for navigation and landing aids (AIL).

Simulated visual landing displays (AIL).

Antenna model range.

Environmental Control and Life Support Subsystem (ECLSS)

Ground cooling (Crew Cabin Integration Laboratory, CCIL).

Control computer (CCIL and Radiator Development Laboratory, RDL).

Data acquisition system (CCIL and RDL).

Vacuum system (CCIL).

Electronic heat loads (CCIL).

Metabolic loads (CCIL).

O_2, N_2, and CO_2 supplies (CCIL).

Facility power (28 VDC +00 H_2 34 120/208).

Thermal-vacuum chamber (RDL).

Main Propulsion Subsystem

Static firing structure with altitude simulate aspirator.

Data acquisition system.

Control computer.

Hydraulic servicing unit.

Air-Breathing Engine Subsystem

Control computers.

Data acquisition system.

Altitude Control Propulsion System

Data acquisition system (ground test vehicle, GTV).

Control computer (GTV).

Ground test vehicle.

Servicing

Cargo handling equipment.

Hydraulic ton jack.

Electric pound hoist.

Cabin vacuum cleaning truck.

Pneumatic ground engine starter.

Engine and hydraulic oil servicing truck.

Servicing truck - aircraft refueling gpm.

Servicing vehicle - hydrant to aircraft refueling gpm.

Hydraulic ground power unit gpm, psi.

Hydraulic fluid servicing unit.

Hydraulic fluid filtering unit.

Cleaning and deicing equipment, aircraft exterior.

Generator set - 400 cycle, 3-phase, volt kva.

Wireless intercommunication system.

Air conditioner Freon cycle.

Tractor - aircraft towing.

Handling equipment - commissary.

Lavatory and waste water servicing equipment.

Auxiliary

Test set - hydraulic fluid particle analysis.

Fuel management system tester.

Brake control system tester.

Brake computer bench tester.

Hydraulic ground power unit, gpm, psi.

Air induction control system tester.

Flight control system tester.

Environmental control system tester.

Central air data system tester.

Central air data system computer tester.

Flight control augmentation system computer tester.

Electrical distribution system analyzer.

Fuel management system tester.

Engine sound suppressor.

Equipment required to check out vehicle systems during manufacturing is listed in Table 5-2.

GSE Listing for Final Assembly and Integrated Checkout

Control Room

- Engine checkout console
- ECLSS/crew checkout console
- Coordinator avionics console
- Junction box modem
- Data bus buffer drivers
- Terminal rack
- USBE checkout console
- VHF FM checkout console
- UHF checkout console
- Up-data link checkout console
- Data bus adapter
- Junction box

Station I, integrated

- ECS freon control console
- Ground cooling cart
- Fuel cell radiator subunit
- Fuel cell heater
- Electrical load bank
- GO_2 distribution and control console
- GH_2 distribution and control console
- Terminal racks
- Multidata bus buffer drivers
- Junction box
- Hydraulic power and service cart
- GN_2 pressure and control console
- H_e pressure and control console

Station II, final mate

- Hydrocarbon analyzer
- Solvent flushing
- Moisture monitor
- Vacuum cart
- Auto partical counter
- ECS freon control console
- Flowmeter bypass valve assembly
- ESC pressure distribution test stand
- Inertial measurement unit coolant-loop
- Helium mass spectrometer
- Freon service cart
- ECS freon volume compensatory
- H_e pressure and distribution console
- Evaporator temperature sensing unit
- GN_2 pressure and control console
- Instrumentation P/S
- Instrumentation stimuli generator
- Docking probe checkout fixture
- Crew module pressure leak rate
- ACPS checkout kit
- Ground power supply
- Mobile data recorder
- External signal conditioner
- Hydraulic cart
- Ground cooling cart
- Fuel cell simulator
- Electrical load bank
- Fuel cell sensor signal simulator
- Aero surface protractor kit
- Electromagnetic test equipment
- Viscoder
- Antenna checkout set

Station III, mate assemblies

- Freon service cart
- Storage bin electrical cables
- Storage bin GN_2 hoses
- Storage bin fluid hoses
- Solvent flush cart
- Rocket engine alignment tool
- Gimbal locking links
- Propulsion system thermocouple test device
- Ground cooling cart
- Mobile data recorder
- External signal conditioner
- Ground P/S
- ACPS checkout kit
- GN_2 pressurization and control console
- Propellant gaging checkout set
- H_e pressurization and control console
- Hydrocarbon analyzer
- Moisture monitor
- Helium leak detector
- Vacuum cart
- Electrical generator for brazing
- Automatic particle counter
- Brazing heads and cable set
- Electromagnetic test equipment
- Visicoder

Table 5-2. Equipment Required for Manufacturing Checkout at the Systems Level

Checkout Requirement	Vehicle electrical simulation unit	He-GN_2 regulator console	Hydrocarbon analyzer	Moisture monitor	Mass spectrometer	Hydro fill and drain regulator	Vacuum cart	Solvent flush panel	Control surface protractor	Hydraulic powercart	Electrical ground power and distributor	Multi switch and measurement unit	Auto circuit analyzer	Flowmeter (gas)	Flowmeter (fluid)	Solvent flush cart	Rocket engine test kit	Keyboard word generator	Optical align set	Electrical cable set	RF switch console	VSWR measurement unit	Precision dc power supply	Data bus actuator unit	Channel chart recorder	Caution and Warning Checkout unit	Binary-to-octal display	Signal select panel	Digital voltohmmeter	Antenna checkout group	RF transmission line set	RF system checkout unit	Modulation checkout unit	VHF checkout unit	S-Band antenna checkout	Bus monitoring recorder	Bus monitoring unit	Variable frequency and volt equalization	Variable electrical load	Fuel cell subsystem unit	Fuel cell sensor simulator	Radiator protect cover	Fluid distribution unit	Water glycol service	Rocket engine alignment set	Engine response recorder	Variable hydraulic load bank	Water glycol flow continuity	Ground cooling cart	A/C hydraulic jacks	GN_2 dry/purge cart	Crew compartment leak rate	Evaporation temperature sensor unit
Body structure		X	X	X	X	X	X	X																																													
Aerodynamics surface									X	X	X	X	X					X																																						
Main propulsion		X	X		X						X		X	X		X	X	X																																					
Attitude control propulsion		X	X		X						X		X	X		X	X	X																																				
Airbreathing propulsion		X	X		X						X		X					X																																				
Orbit maneuver		X	X		X						X		X	X		X	X	X																																				
Guidance, navigation											X		X						X	X	X																																	
Data control management											X		X							X	X																																
Displays and controls						X														X		X																														
Communication											X		X							X		X							X																							
Electrical power distribution											X		X							X		X																															
Software	X																																																					
Electro-mechanical power generator		X	X	X	X		X						X				X		X	X																																	
Hydraulic power		X								X			X						X	X																																	
ECSLSS		X	X	X	X		X						X				X		X	X																																	
Flight personnel provisions											X																																									
Landing system		X								X		X		X				X		X																																
Payload deployment										X		X		X				X		X																																
Docking										X		X		X				X		X																																

6.0 LONG-LEAD-TIME FACILITY AND EQUIPMENT ITEMS

6.0 LONG-LEAD-TIME FACILITY AND EQUIPMENT ITEMS

To ensure the timely acquisition of space shuttle facilities, long-lead-time requirements have been studied. These studies should be considered preliminary until the vehicle design, test plan, and manufacturing plan are finalized. The preliminary long-lead-time requirements are presented in the following paragraphs.

6.1 PRODUCTION FACILITIES

To support fabrication and assembly operations, the planning and modifications of NASA buildings at Seal Beach and Downey will commence at contract award. The following buildings will require minor modifications to support operations indicated and are listed in order of need by site.

Seal Beach

Building S-02	Tank assembly
Building S-14	Forward fuselage
Building S-03	Aft fuselage
Building S-18	Intermediate fuselage
New building	Final assembly

The planning and construction of this NR-funded building is recognized as a long-lead-time item. Specific items within this building project demanding early attention are electrical switchgear, air conditioning compressors and air handling equipment, structural steel, and bridge cranes and hoists. It is expected that development of A&E criteria will begin at Phase C contract award.

Downey

Building 001	Tooling/crew module assembly
Building 290	Crew module checkout

Tulsa

Building 001	Intermediate fuselage

6.2 DEVELOPMENT TEST AND FLIGHT TEST

The Facilities requirements for development ground testing and flight testing will be determined through the preparation of preliminary engineering reports (PER's), which will establish criteria for design. These specialized facilities require large-scale construction periods of one to three years.

Projected schedules for design, construction, and activation indicate the need for PER funding four to six months after Phase C award.

The projects that have been identified to date by site are as follows:

Seal Beach	
Static Test Tower	Cryogenic - hydrostatic test
Downey	
Building 260	Crew module - pneumostatic test
WSTF	
Test Area 400	Propulsion and power generation systems testing
KSC	
LC-39A	Main propulsion cluster firing test
MSFC	
Building 4619	Structural test
Point Mugu	Preflight testing
Required:	Dock facility and barge
Edwards AFB	Horizontal flight test
Required:	Safing area

6.3 LAUNCH OPERATIONS FACILITIES

As indicated in the facility implementation schedule, approximately nine months is required for the processing of a preliminary engineering report by selected contractors. Based on the present program schedule, this PER effort will be started no later than the award of the shuttle Phase C contract.

The projects that have been identified to date are as follows:

KSC

Operations Building (assembly and test area)	Modify
Flight Crew Support and Training Building	Modify
Vertical Assembly Building	Modify and enlarge for maintenance and checkout
Launch Control Center	Modify
Launch Pads 39A and B	Modify
Industrial water facility	Modify
Airfield runway	New
Safing area	New